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A SYNOPSIS OF COMETARY SPECTRA

By FRANK S. HOGG

During the past sixty years many observations of comets have been obtained, giving contradictory results as to their physical composition and behaviour. Much of the difficulty is caused by the large inherent differences between the comets themselves. The purpose of this investigation was to find the average spectrum of the head of a comet, and determine its dependence on the heliocentric distance. While the ideal way to investigate such a problem is to secure accurate, photometrically standardized plates, it would be years before enough comets appeared to give a representative mean. On the other hand all the old observations are available, and, despite the roughness and uncertainties in the intensity estimates, they are sufficiently numerous to smooth out most of the differences between the comets, or inaccuracies of the observations. Further, these estimates of intensities are the only data we have on the spectra of this large collection of comets.

I. THE OBSERVATIONAL MATERIAL

It was my intention to use all the observations of cometary spectra made since the first spectroscopic observation of a comet by Donati,[1] in 1864. Both visual and photographic spectra are included, as obtained with slit or objective prism forms of instruments. Data have been secured on the spectra of 94 comets, represented by 830 observations, discussed in 410 papers. The distribution of the material is shown in Table I, where for each comet the number of

available reference works is given. The survey of the literature has been made much easier and more complete by the aid of a recent bibliography, compiled by Baldet.[2]

TABLE I

OBSERVATIONS OF COMETARY SPECTRA

Comet	Refs.	Comet	Refs.	Comet	Refs.	Comet	Refs.	Comet	Refs.
1864a	1	1879a	10	1888a	6	1899a	1	1913f	4
1865f	2	1879d	4	1888e	2	1899d	1	1914b	6
1867b	1	1880e	6	1889e	1	1901a	1	1914d	1
1868a	6	1880f	4	1889g	1	1902b	2	1914f	1
1868b	5	1881b	35	1890a	1	1903c	4	1915a	4
1869a	1	1881c	10	1892a	4	1904a	1	1916b	1
1870a	1	1881d	2	1892d	1	1907c	12	1917a	3
1871a	3	1882a	21	1892f	5	1908c	19	1919b	1
1871c	4	1882b	17	1893b	6	1909c	25	1921a	2
1871d	1	1883a	5	1893c	2	1910a	14	1924b	1
1873c	2	1883b	13	1894b	2	1910e	1	1924c	2
1873d	3	1884b	1	1895c	1	1911b	8	1925c	3
1874b	5	1884c	1	1895d	1	1911c	19	1925d	2
1874c	19	1884d	1	1896a	1	1911f	5	1925j	1
1874d	1	1885a	1	1896b	1	1911g	3	1925k	1
1875a	1	1885d	5	1896c	1	1912a	8	1927c	1
1877a	3	1885e	2	1898b	1	1913a	1	1927d	1
1877b	6	1886c	1	1898d	1	1913b	1	1927k	2
1877c	1	1886f	1	1898f	1	1913e	1		

The heliocentric distance of the comet was determined for each of the 830 observations. This was found with sufficient accuracy by interpolation in the best of the predicted ephemerides, taken chiefly from the *Astronomische Nachrichten* for the early comets, and, from the *Ephemeriden-Zirkular der Astronomische Nachrichten,* the *Astronomical Journal,* and *Popular Astronomy,* for more recent ones. The distribution of the spectral observations with heliocentric distance is shown in Figure 1. The great frequency of the observations at distance 0.7 units is mainly due to some fifty observations of comet 1881b at perihelion. Apart from this, the most striking feature of the distribution is that the spectra were much more often observed before than after perihelion. This asymmetry was the reverse of what was expected, as comets are likely to be discovered when near perihelion, after which, in general,

they tend to brighten. Both these tendencies should give preference to observations after perihelion, an effect that is clearly shown by reference to the actual duration of observation of comets, as tabulated in Valentiner's Astronomy.[3]

Of the comets appearing between the years 1880 and 1900, twenty-six per cent. were seen for a longer time before, and seventy-

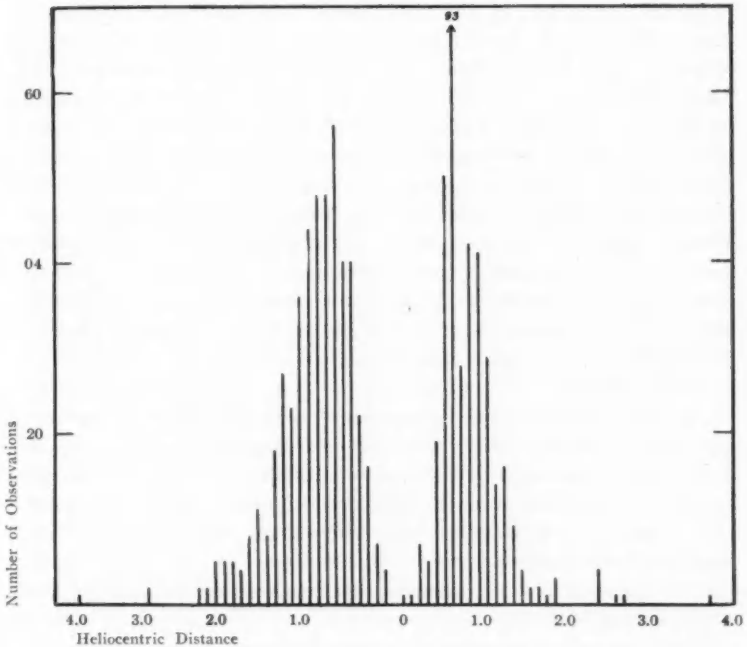

Figure 1.—The distribution of spectroscopic observations of comets with heliocentric distance. Ordinates are numbers of observations; abscissae are heliocentric distances. The left hand side of the figure applies to observations made before, and the right to those after, perihelion.

four per cent. for longer after perihelion passage. The explanation of the opposite effect in the spectroscopic observations is probably that if the first few observations of a comet failed to show any change in the spectrum, the program was discontinued. This is

especially regrettable in the case of comets at distances greater than 1.5 units, as for these the observations become too few to furnish a representative mean.

The material itself is rather heterogeneous. The wave length measurements are for many comets very good, so that identification of the emissions is fairly definite. For the brighter comets, with an appreciable background of reflected solar light, the identification is somewhat simplified by the presence of the Fraunhofer absorption lines. The work of several early observers is especially noteworthy. Copeland and Lohse,[4] and Thollon and Gouy,[5] for example, determined the Doppler shift of the D lines of sodium in comet 1882b as corresponding to a velocity of between 61 and 76 km per second. From the orbital elements, the line of sight velocity has since been computed as 73 km per second. Later Albrecht[6] succeeded in making such good wave length determinations in the spectrum of comet 1910a that he suggested the possibility of using velocity measures as an aid in the computation of orbital elements, especially for comets close to the sun. Not only do such comets lend themselves to more accurate determination of radial velocity, but also their orbits are in general more difficult to determine by the ordinary position methods.

In general the photometric aspect of the observational programs has been badly neglected. An exception is found in the work of Rosenberg,[7] who measured the actual distribution of energy in the continuous background of the spectrum of comet 1908c. He found that it represented an object much bluer than Vega—bluer, in fact, than the hottest stars known. The existence of a "violet type" continuous spectrum for many comets has recently been confirmed by Bobrovnikoff.[8]

The lack of photometric data greatly increases the difficulty of interpreting the intensity estimates. The observations themselves are greatly influenced by resolving power, atmospheric and instrumental absorptions, contrast effects against the dawn, daylight, and twilight skies, and visual and photographic color sensitivities. Further uncertainty is introduced by the personal equation of the observer in his intensity estimates, and by the varying explicitness of the published descriptions of the spectra. Most of these diffi-

culties may be minimized by using only those average intensities derived from a considerable number of observations, and by making estimates relative to the continuous background.

II. Lines and Their Occurrence in Cometary Spectra

A survey of the observations shows that altogether 187 lines or band heads have been recorded and measured. As this paper deals with the *average* spectrum of the head of a comet, it was decided that any lines occurring in less than six per cent. of the comets observed in the range of heliocentric distance considered, should be excluded as being rare or doubtful. Owing to the definite changes in spectrum when the comet comes very close to the sun, a group was formed of observations made within 0.4 units of the sun. Some of the lines which do not satisfy the occurrence criterion for the whole set of observations are sufficiently frequent at small heliocentric distances to justify their inclusion in the innermost zone. Table II contains a summary of the lines which satisfy the condition for definite occurrence. In the case of band groups, the individual sub-heads are not listed separately; a single entry for the head of the group is made. In this way the table of emissions is further reduced to fifty-three entries. For the whole number of comets, and separately for those within 0.4 units of the sun, the mean intensities are given, and also the percentage of comets in which the radiations are present. The letters following the intensities show the character of the lines, according to Fowler's notation.[9] The designations are: n, nebulous, diffuse; b, broad; and v, broad, diffuse towards the violet. The remaining columns give the identification of the line, its laboratory wave length, and remarks. It might again be noted that this paper deals with the spectrum of the head of the comet only; hence the characteristic tail bands of comets, such as N_2+ at 3914, and $CO+$ at 4722, 4576, 4279, and 4023, are not included in Table II. Such tail bands are tabulated by Baldet.[10]

Molecular spectra are represented in the emission spectra of comets by three known band systems, of carbon, cyanogen, and some unknown hydrocarbon which gives rise to the Raffety bands[11]. Of the 187 emissions found in cometary spectra, 31 are subheads of

TABLE II

EMISSION LINES AND BANDS IN COMETARY SPECTRA

λ	All comets Int.	%	Comets $r<0.4$ Int.	%	Ident.	Lab. λ	Remarks
3590	1v				*CN*	3590	$^2S-{}^2S$, sequence −1; red limit
3883	8v	91	8v	75	*CN*	3883	$^2S-{}^2S$, sequence 0; red limit
3911	1	9			*	3912	
3988	2	18			* *	3988	
3992	2	18			* *	3993	
4000	2	12			* *	4000	
4003	2	12			* *	4003	
4013	3	18			*	4013	
4019	3	32			*	4019	
4099	2	12			*	4099	
4109	4v	71	2v	33	*CHx*	4109	Raffety Hydrocarbon bands; red limit
4125	1	15			*	4125	
4138	3	9			* *	4139	
4216	3v	62	4v	33	*CN*	4216	$^2S-{}^2S$, sequence +1; red limit
4234	3	15			*	4234	
4255	2	15			* *	4255	Double in sun; 4253, 4257
4290	3	15				4290	Broad bright region in solar spec-
4292	2	9			*		trum from 4290 to 4298
4298	3	20				4298	
4301	3	12			*	4301	Faint in sun, but superposed on
4304	1	15			*	4306	dark region
4314	5	35			* *	4317	Very broad bright band in the sun
4335	1	15			* *	4332	Very broad bright band in the sun
4350	2	15			* *	4348	Very broad bright band in the sun
4381	3v	52	4v	67	C_2	4381	Swan spectrum; $^3P-{}^3P$, sequence −2; red limit
4477	2	9			* *	4477	
4606	2v		2v		*CN*	4606	$^2S-{}^2S$, sequence +2; red limit
4724	1	9			*	4725	
4737	5v	92	5v	57	C_2	4737	Swan spectrum; $^3P-{}^3P$, sequence −1; red limit
5165	8v	95	8v	57	C_2	5165	Swan spectrum; $^3P-{}^3P$, sequence 0; red limit
5203			2	14	*Cr*	5205.2	1^5S-1^5P, $E.P.=0.94$ volts
5207			2	14	*Cr*	5208.4	5203 corresponds to the laboratory double 5206.0, 5204.5
5269			4	14	*Fe*	5269.5	
5329			4	14	*Fe*	5328.0	Five of the strongest lines of the
5369			2	14	*Fe*	5371.5	multiplet $1^5F-1^5D^\circ$, $E.P.=0.94$
5395			4	14	*Fe*	5397.1	volts
5428			4	14	*Fe*	5429.7	
5474			1	14	*Ni*	5476.9	Isolated line; a^1S-a^1P, $E.P.=1.82$ volts
5574			2bn	14			These lines are broad, and diffuse, in
5601			2bn	14			contrast to the sharp, identified metallic lines
5635	5v	92	5v	57	C_2	5635	Swan spectrum; $^3P-{}^3P$, sequence +1; red limit
5797			3bn	14			Similar to 5574, 5601
5890	7	11	10	57	*Na*	5890.0	The ultimate lines of sodium,
5896	4	11	6	57	*Na*	5895.9	1^2S-1^2P
5900			1n	14			Narrower than 5574
5922			3	14			
5934			3	14			Two pairs of sharp, well measured
5953			2	14			lines
5963			2	14			
6028			1n	14			Narrower than 5574
6191	2v	10	2v	14	C_2	6191	Swan spectrum; $^3P-{}^3P$, sequence +2; red limit
6495	2v				*CN*	6495	$^2P-{}^2S$, sequence −1; strongest subhead

* * Identified with solar "emission lines", as described in the text, by the first method.
* Probably solar (second method).

the five band groups of cyanogen, 22 are subheads of the five band groups of the Swan spectrum of carbon, and nine of the remainder may be identified, as suggested by Baldet,[12] with the Raffety bands. As may be seen from the table, these bands are of very general occurrence over the range of heliocentric distance here considered.

The spectra of the elements are less common. The most conspicuous lines are the two D lines of sodium. Their identification is very certain, although many of the observers have not had sufficient resolving power to separate them. The remaining line spectra depend on the observations of the great comet, 1882b, and in particular on the very precise work of Copeland and Lohse,[13] who identified five of the seventeen new lines as being due to iron, and suggested the identification of other cometary lines with the same element. Orlov[14] confirmed their identification of the five lines between 5429 and 5269 A, the stronger lines of the multiplet $1^5F - 1^5D'$, of excitation potential 0.94 volts. He further associated the cometary line 5474 with the strong isolated nickel line 5477. The identification seems fairly certain, despite the discrepancy in wave length. The pair of lines 5203 and 5207, of approximately equal intensity, possibly corresponds to the $1^5S - 1^5P$ multiplet of chromium. This multiplet has three strong lines, 5208.4 (300r), 5206.0 (200r), and 5204.5 (150r), and might appear as a close double, the two more refrangible of the three lines being unresolvable. The mean wave length error is 1.8 A. Of the nine remaining unidentified lines recorded by Copeland and Lohse, four are sharp, and resemble the metallic lines, and the remainder are broader and somewhat diffuse.

The unknown lines in the photographic region have not been assigned to emission spectra of molecules or atoms. Their appearance on reproductions of some good slit spectrograms strongly suggested the possibility of their being merely narrow, more or less continuous regions of the reflected solar spectrum, contrasted with neighboring Fraunhofer lines. The possibility of mistaking such regions of the background for true emission is increased by the fact that the slightly diffuse edges of the nucleus of the comet give a rather ragged appearance to the edges of the continuous spectrum, as obtained with a slit spectrograph. In other words, the brighter

parts of the continuous spectrum have effectively a larger nucleus, and hence their "emission lines" appear to be longer. This relation between the length of a line and its intensity is the same as is found in the subheads of an emission band group. Campbell[15] realised this difficulty in dealing with his spectra, and mentioned the possibility of one observer finding such an emission line where another does not record it in an examination of the same plates.

To overcome this difficulty the following attempt has been made to estimate the probability that these lines are spurious. Solar spectra of a dispersion comparable to the usual cometary spectra were photographed by means of a Hilger medium quartz spectrograph, dispersion 50A per mm at H_γ. Mr. H. H. Plaskett and the writer independently examined these spectra and selected the most conspicuous "emission lines", regarding the solar spectrum as an emission spectrum. Such regions were usually from one to three Angstroms in width, free from, but bordered by, conspicuous Fraunhofer lines. In the regions free from the prominent cometary band groups of carbon and cyanogen, where fainter cometary lines have not been detected in comets, we selected the fifteen "emission lines" of the solar spectrum which seemed most conspicuous with the dispersion used. The independent lists agreed very closely. The wave lengths of the lines so marked,—determined approximately by comparison with the solar spectra of Huggins' Atlas,[16] and then more definitely from Rowland's maps of the solar spectrum,—were compared with those of the twenty-two unknown lines of the photographic region of the cometary spectra. Of the fifteen solar lines so selected, ten correspond to ten of the stronger lines of the cometary spectra. As these regions of the continuous spectrum were selected entirely without reference to the cometary lines, without a wave length scale, and independently by two observers, it would appear that this identification of these ten unknown lines is at least highly probable. Such identifications are indicated by the symbol * * in Table II.

This left twelve unknown lines in the photographic region which had not been picked up in our first survey of the solar spectrum. Huggins' short dispersion spectra, with wave length scale, were then examined for possible coincidences between continuous regions of

the solar spectrum and cometary lines. The wave lengths of such regions were then taken more accurately from Rowland's maps. This method has not the same freedom from bias as has that of the previous paragraph, and the identifications are much less certain. However, in the light of the facts that the better method identified ten of the stronger lines as being continuous regions of the background, and that all the remaining lines coincide with similar though less conspicuous regions, it seems highly probable that the unknown lines are due to reflected solar light, rather than to intrinsic light of the comet itself. Such an explanation cannot account for the remaining nine unidentified lines, which occur in the visual region, where the Fraunhofer lines are much weaker and less frequent, and hence the background is more continuous.

In connection with Table II it is interesting to note that there is little justification for the statement, appearing rather frequently, that lines of the *b* group of magnesium are found in the spectra of certain comets, at small heliocentric distances. Observers have occasionally reported the presence of these lines, but other observations with better equipment seem to show that this emission is probably merely the bright head of the fourth group of the Swan spectrum of carbon, at 5165A. Suggested identifications of lines or bands of the spectra of lead and manganese are still less well founded.

III. On the Cometary Spectrum as a Function of Heliocentric Distance

For the intense emissions that occur most frequently, an attempt has been made to examine dependence on distance from the sun in rather more detail than is given in Table II. For this purpose the space around the sun was divided into concentric spherical zones of thickness one-tenth of an astronomical unit. These zones were then numbered outward $0<r<0.1$, zone 0, $0.1<r<0.2$, zone 1, and so forth.

In the study of the original reference papers, abstracts were made of each observation of each comet. These were then examined with a view to determining the actual appearance of the spectrum in any particular zone. It was at this stage of the program that

the differences in the appearance of the spectrum, as dependent on the instrument, caused the greatest difficulty. Thus, for example, the strength of the *CN* (3883) band is very dependent on absorption by the instrument and the atmosphere, while the Swan band at 5165A is comparatively free from such difficulties, but occurs in the most insensitive region of the ordinary panchromatic plates. For such reasons numerical intensities and weights were not always assigned to each observation, in combining them to form a composite observation of the spectrum of the comet for one particular zone. A general idea of the actual appearance of the spectrum of each comet, in each zone, was formed, making allowances for the nature of the equipment, and the technique employed in the various observations.

The intensities in such a composite spectrum were then estimated relative to the adjacent continuous background. Numerical values of from zero to four were assigned. An emission which was too faint to be detected against the continuous spectrum was denoted by 0. The intensity 4 indicated that the emission was very strong with respect to a weak or apparently absent background. The intermediate steps, 1, 2, and 3, were used to grade the contrasts of the emissions between these limits. It should be noted that the intensities here used differ from those found in Table II, which run from 0 to 10, in accordance with the customary notation. On account of the heterogeneous nature of the material used in this section of the work, it seemed somewhat artificial to subdivide the intensities into more than these five grades. In the composite observations, intensity estimates were made on the four Swan bands of carbon, two bands of cyanogen, the Raffety hydrocarbon bands, and the D lines of sodium. Further, the presence of the Fraunhofer lines in the continuous background was recorded when detected.

These composite observations form the basis of the study of the variations of the spectrum of the average comet with heliocentric distance. Using such a set of observations is equivalent to introducing an arbitrary system of weighting the original observations. To have used the direct observations would have given almost all the weight to a few very bright, well observed comets, such as Halley's, 1909c, which was observed about 150 times, and comet

1881b, which was observed 100 times, and the relation found would have been between the average observation and the heliocentric distance. On the other hand, as for Table II, all the comets might have been given equal weight, and the average spectrum found. Intermediate between these two methods is that adopted in this section of the paper, namely, that of giving all the composite observations equal weight. By this method each comet enters with a weight equal to the number of zones in which it was observed. Thus Halley's comet was observed from 2.9 units, through perihelion, and back out to 1.3 units. Observations were actually made in twenty-two zones, and hence the spectrum contributes twenty-two composite observations to the study. Similarly, comet 1881b is now represented by ten observations, while many of the other comets enter but once, being observed over but a small arc of their orbits.

The mean intensity of each emission at each distance was then determined by taking the arithmetical mean of the intensities of all

TABLE III

INTENSITIES OF EMISSION LINES AS A FUNCTION OF HELIOCENTRIC DISTANCE

	Visual Region							Photographic Region					
				Intensities					Intensities				
r	No. of Comets	% Fraunhoffer	No. of Comets	*Na* 5893	C_2 5635	C_2 5165	C_2 4737	No. of Comets	C_2 5635	C_2 5165	*CN* 4216	*CN* 3883	*CHx* 4108
0.1–0.2	3	67	3	3.7	0.0	0.3	0.0	2	0.0	0.0	0.0	0.0	0.0
0.2–0.3	3	100	3	2.3	0.0	0.0	0.0	2	0.0	0.0	0.0	0.0	0.0
0.3–0.4	8	25	6	2.0	1.2	2.3	1.0	3	2.0	1.0	0.7	3.3	0.3
0.4–0.5	8	25	5	2.2	1.0	1.8	1.0	4	2.0	0.2	0.2	3.0	0.2
0.5–0.6	14	42	12	0.9	1.8	3.1	1.5	6	1.8	0.5	1.0	2.7	0.3
0.6–0.7	23	8	19	0.1	1.5	3.0	1.4	8	2.8	0.8	1.1	3.4	0.8
0.7–0.8	27	11	23	0.1	1.7	3.2	1.8	13	2.5	0.2	0.5	3.6	0.9
0.8–0.9	20	25	19	0.0	1.2	3.4	1.6	6	2.8	0.8	1.2	3.3	1.5
0.9–1.0	23	17	21	0.0	1.6	3.5	1.8	7	2.4	0.3	0.4	2.4	1.0
1.0–1.1	29	14	22	0.0	1.6	3.4	1.4	11	2.2	0.3	0.5	2.6	1.5
1.1–1.2	27	11	22	0.1	1.6	3.5	1.7	12	2.5	0.8	0.9	2.8	1.2
1.2–1.3	15	20	11	0.0	1.4	3.3	1.5	6	2.5	1.0	0.8	3.0	0.8
1.3–1.4	16	0	10	0.0	1.2	3.1	1.3	7	2.6	0.7	0.9	3.7	1.4
1.4–1.5	9	11	5	0.0	1.4	3.4	1.8	5	2.8	0.4	0.6	3.2	1.8
1.5–1.6	8	0	6	0.0	1.3	3.2	1.5	2	3.0	0.5	0.5	2.5	1.0
1.6–1.7	5	20	4	0.0	2.0	3.5	2.2	2	2.5	1.0	1.5	3.5	1.5
1.7–1.8	10	0	7	0.0	1.3	2.6	1.0	3	2.7	0.7	0.7	3.3	1.7
1.8–1.9	4	0	4	0.0	2.0	3.2	1.0	0	—	—	—	—	—
1.9–2.0	5	0	4	0.0	1.5	3.2	1.5	1	2.0	0.0	0.0	2.0	1.0
2.0–2.1	3	0	2	0.0	0.5	1.5	1.0	1	2.0	0.0	1.0	3.0	2.0
2.1–2.2	3	0	2	0.0	1.0	2.5	0.5	1	2.0	0.0	1.0	2.0	1.0
2.2–2.3	2	0	0	—	—	—	—	2	2.0	0.5	0.5	3.0	1.5
2.3–2.4	1	0	0	—	—	—	—	1	0.0	0.0	0.0	1.0	0.0
2.4–2.5	1	0	1	0.0	0.0	0.0	0.0	0	—	—	—	—	—
2.5–2.6	0	—	0	—	—	—	—	0	—	—	—	—	—
2.6–2.7	1	0	1	0.0	0.0	0.0	0.0	0	—	—	—	—	—
2.7–2.8	1	0	0	—	—	—	—	1	1.0	0.0	0.0	0.0	0.0
2.8–2.9	0	—	0	—	—	—	—	0	—	—	—	—	—
2.9–3.0	1	0	1	0.0	0.0	0.0	0.0	1	0.0	0.0	0.0	0.0	0.0
3.7–3.8	2	0	1	0.0	1.0	2.0	1.0	1	1.0	0.0	0.0	1.0	0.0

the composite observations in the zone considered. Table III gives, in the first three columns, the limits of the zone, the total number of composite observations entering into the mean, and the percentage of these observations in which the Fraunhofer lines have been observed. The next five columns refer to the visual observations, and give the number of comets observed visually in each zone, and the mean intensities of the emissions of this region. The remaining six columns give similar data for the photographic range of the spectrum.

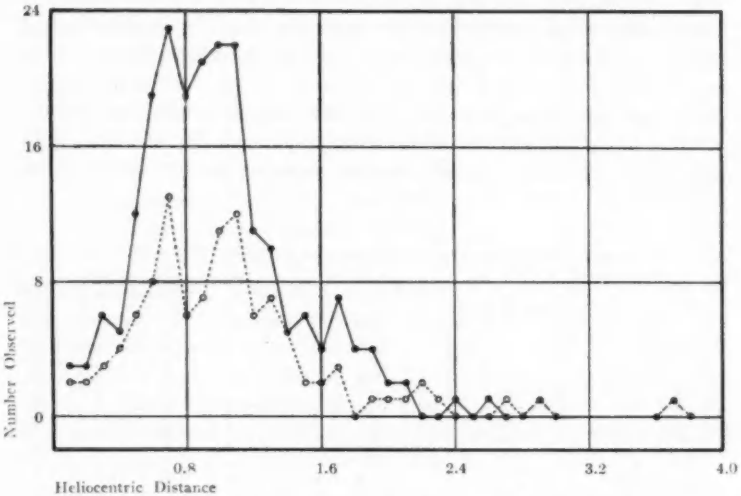

Figure 2.—The distribution of the composite observations (number of comets observed at any distance). Ordinates are numbers of comets, and abscissae, heliocentric distances. Solid and broken lines represent visual and photographic observations, respectively.

The frequency distributions are found from the second, fourth, and ninth columns of the table, and are shown graphically in Figure 2. The 830 separate observations reduce to 271 composite observations. As some comets were observed both visually and photographically at the same distance there are altogether 213 visual and 108 photographic composite observations. The preponderance of visual observations is chiefly due to the number of bright comets,

observed over long distances, during the thirty years before photographic observations became practicable. The two frequency curves show a very peculiar minimum of comets at a distance of 0.8 units. This is much more marked in the photographic observations, but is present also in the visual material.

The Fraunhofer lines are of special interest in that they give an indication of the nature of the continuous spectrum of the background. In Figure 3 the percentage of comets in which these lines have been observed is plotted as a function of heliocentric distance. The lines are found to be of more frequent occurrence at small distances. They are present, however, at distances as great as 1.6 units. There is a strong observational selection which operates against the detection of Fraunhofer lines at great heliocentric distances; our values of the percentage occurrence of these lines in the comets are based on all the observations of cometary spectra,

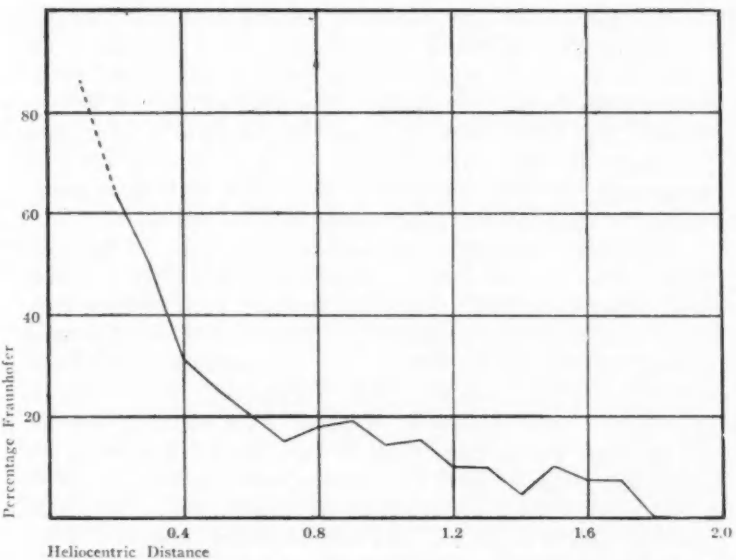

Figure 3.—The percentage of comets in which the Fraunhofer lines have been detected (ordinate), as a function of heliocentric distance (abscissa).

regardless of the instruments employed. As the more distant, faint comets are much more easily observed with an objective prism camera, or a widely opened slit spectroscope, the Fraunhofer lines are almost certain to escape detection. The bright comets near to the sun are observable with instruments of high resolving power, and the absorption lines are fairly obvious. Thus the chance of detecting a Fraunhofer line of a certain intensity decreases as the distance of the comet increases. The true occurrence of these lines must then be greater than the observed occurrence, and the difference between the two increases with the heliocentric distance. From Figure 3 we should thus conclude that the absorption lines of the solar spectrum are of fairly general occurrence out to at least 1.6 units.

The presence of the Fraunhofer lines over a great range of heliocentric distance is interesting in connection with the recent work of Bobrovnikoff,[17] who found that at distances greater than 0.7 units the "violet type" spectrum predominates, and that only at distances less than this is the reflected light very strong. The presence of the absorption lines out as far as 1.6 units must indicate that the violet spectrum is confined to a relatively narrow band of radiation, superposed on the spectrum of the reflected solar light. Its source is unknown; as it is absent at small distances, it may be a band group belonging to a molecule of such low dissociation energy that it is all dissociated at distances less than 0.7 units.

The probable prominence of reflected solar light in the background of the cometary spectrum is important in that our emissions are estimated with respect to this background. Their absolute value is thus affected by the variation of the brightness of the continuous spectrum with heliocentric distance. If the continuous spectrum is directly due to reflected solar light, its intensity should vary as $1/r^2$, where r is the heliocentric distance. As a matter of observation, the total comet light seems to vary rather irregularly, and usually depends on a power of r rather greater than 2. The work of Holetschek,[18] on the magnitudes of comets, shows that in all cases the index 2 is too low, and that something between 3 and 4 is probably an average. Van Biesbroeck,[19] using very good photographic determinations, suggests that Encke's comet varies in

brightness as $1/r^6$, rather than $1/r^2$. Comets differ greatly, and the law is in each case quite empirical. The departure of the intensity variations from the inverse square law may be explained in either of two ways. As all of the measures refer to the integrated light of the comet, they include the variations of the emission spectra, as well as those of the continuous, reflected background. If the intensity of the emissions is increasing relative to the continuous spectrum, as the comet approaches the sun, the integrated light of the comet would give something of the effect observed, namely, a greater variation than that predicted from the $1/r^2$ law. Further irregularities in the variation of the reflected part of the comet's light may arise from a change in the amount of reflective surface of the cometary head, due to disintegration of the particles of the head of the comet. Such increase of surface is caused by the sun's radiation, and hence may vary as $1/r^2$. The resultant intensity would then vary as $1/r^4$. Awaiting definite photometric data on the variations of the intensity of the continuous, reflected background, we shall assume that our intensities are relative to a spectrum which varies as $1/r^2$.

The D lines of sodium, as shown in Figure 4, in general appear at $r=0.8$ units, and increase in intensity very rapidly with decreasing heliocentric distance. Up to a distance of one-tenth there is no decrease in the gradient, and probably at closer approaches the D lines would become even more striking. One comet, 1911c, showed these lines at a distance of 1.1 units. No other comet has shown them at distances greater than 0.8 units, so that this appears to be an exceptional case, and is probably due to some physical peculiarity of the comet which favours a larger number of sodium atoms in the coma than is usually found. Such possible differences are confirmed by the fact that some comets show little or no sodium emission at small heliocentric distances.

The intensity of the D lines is dependent not only on the heliocentric distance of the comet; there is definitely a smaller variation superposed on the main variation in certain comets. Halley's comet, 1909c, for example, had D lines which varied rapidly from night to night when the comet was near perihelion. Moreover there is some evidence for the existence of a secular variation in the spectrum

of this comet. The spectrum has been observed at but one return; the previous appearance, in 1835, was before the advent of spectroscopic observations. Some idea of the spectrum may, however, probably be obtained from the colour of the comet. Usually the colours have little meaning, in that they are influenced by the conditions of observation and by prejudices of the observer. However, from descriptions of the past appearances [20, 21] of Halley's

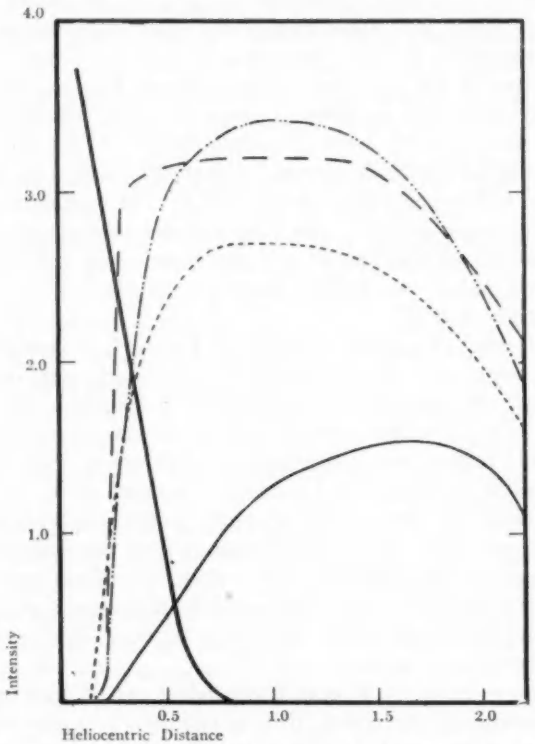

Figure 4.—The relation between line intensity (ordinate) and heliocentric distance (abscissa). The heavy solid line represents Na 5893; the light solid line, CH_x 4108; short dashes, C_2 4737; long dashes, CN 3883; dashes and dots, C_1 5165.

comet, it seems probable that in 1456, 1531, 1607, and 1835 the comet was of a yellowish colour; in 141, 1145, and 1910 it was bluish white. If, as for some of the brighter comets, the yellowish colour is associated with the presence of strong D emission, it would appear possible that the intensity of the D lines in Halley's comet varies from one perihelion passage to another.

The Swan bands of carbon, recently attributed to the neutral C_2 molecule by Pretty[22] and regarded by Christy and Birge[23] as a $^3P - {}^3P$ transition, are represented by two curves in Figure 4. They are apparently very weak or absent at heliocentric distances less than 0.3 units, increase very rapidly in intensity from there outward, and have a long flat maximum at about one unit. They gradually fade out with respect to the continuous spectrum. As the C_2 (5165) band is dependent on visual and panchromatic photographic observations, and the C_2 (4737) band on ordinary photographic observations, the curves are based to a considerable extent on different comets. The general agreement between the two curves is very satisfactory. Beyond a distance of 1.8 units the observed comets are too few to give a mean which is free from the peculiarities of the individual comets and estimates.

The cyanogen band, CN (3883), follows the same type of curve as does the Swan spectrum. The intensity of this band is greater than that of C_2 (4737). As the cyanogen at 3883A suffers much more from instrumental and atmospheric absorptions, it would appear that it is on the average much stronger than C_2 (4737), at all distances discussed. The rapid decrease in intensity between 0.4 and 0.2 units may be partly due to the difficulty in photographing so far into the violet against a daylight sky. On the other hand, the curve is very similar to that for C_2 (5635) and C_2 (5165), where such difficulty is not encountered. The dissociation heat of the CN molecule is 9.5. volts, as compared with 7.0 volts for C_2.

The Raffety hydrocarbon bands, CH_x, behave in a rather different manner. Absent within the two inner zones, they increase in intensity very gradually, as compared with the Swan and cyanogen spectra, and reach a maximum much further out. They have not been observed beyond 2.3 units from the sun. They are weaker than the CN (3883) band throughout the whole range. Comparing

the Raffety bands with the *CN* (4216) band, it is seen that the former are the stronger at distances greater than 0.8 units, and the latter at distances less than this. The exact carrier and dissociation potential of these bands of hydrocarbon are unknown.

IV. Predicted Cometary Spectrum at Small Heliocentric Distances

From the data of Tables II and III it is possible to predict the emissions in the spectrum of a comet which reaches a very small heliocentric distance. There are three necessary conditions for the occurrence of the spectrum of an element in the cometary spectrum. There must be a reasonable abundance in the head of the comet of the element considered; it must be sufficiently volatile or must be present in a volatile compound, to insure its presence in the gaseous state; and it must have low-excitation lines in the observable region of the spectrum. From the general analogy between comets and meteors, it seems reasonable to suppose that the elements of the greatest abundance in the known meteorites should be well represented in the composition of the nuclei of comets. The limiting excitation potential is somewhat indefinite.

Zanstra,[25] in his work on the luminosity of comets, has shown that the excitation of the atoms of the heads of comets is probably accomplished by their absorption of the solar light incident on them. For resonance lines the light absorbed is of the same wave length as that emitted; for all other lines the light absorbed is of shorter wave length. The intensity of the emission lines will then depend on the intensity of the solar light available for absorption. We have assumed that the limiting intensity of the incident light required to produce detectable lines in the cometary spectrum is equal to one-fifth of the intensity of the solar light at the D lines of sodium. From the black body curve for the sun (6000°), it is found that the wave length of light of such intensity is not less than 2315A. Thus lines must have as the maximum excitation potential at their upper level the potential corresponding to 2315A, 5.33 volts, if they are to attain the required detectable intensity. Further, as a line absorbed may give rise to several emission lines, this intensity is in

all cases an upper limit rather than a predicted intensity. The more lines there are which have a common upper excitation, the smaller will be the intensity of the individual lines.

The first four columns of Table IV give the physical data for the most abundant elements, as determined from chemical analysis of meteorites. Successive columns give the element, the average percentage by atoms in stone and iron meteorites, from the summary by Shapley and Miss Payne,[26] and the boiling point, at normal pressure. The following seven columns contain the necessary spectroscopic data for these elements: the excitation potentials of the upper and lower levels of the strongest multiplets which occur in the accessible region of the spectrum and have excitations less than the limiting value of 5.33 volts, the wave length, intensity, and King's temperature class for the strongest line of each of these multiplets, the multiplet designation, and its wave length range. The elements are arranged in order of abundance in stone meteorites, and the multiplets in order of their upper excitation levels. The accessible region was taken as extending from 3900 to 6500A. The spectroscopic data are chiefly taken from Russell's list of ultimate and penultimate lines[27]; more recent analyses of nickel, by Bechert and Sommer,[28] of copper, by Shenstone,[29] and of cobalt, by Catalan and Bechert,[30] have been used.

The comets in which the metallic emission lines have been found have been very poorly observed in the photographic region, so that our knowledge of spectra at small heliocentric distances is restricted to the visual range. From Table IV it is evident that the lines of iron, nickel, sodium, and chromium which have been detected in comets are, for each of these elements, exactly the lines which should be the most conspicuous in the visual region. Further, with the possible exception of the carriers of the nine so far unidentified lines, there are no elements represented in the spectrum of the comets which would not be predicted from the composition of meteorites.

The absence of the *b* group of magnesium is interesting. As its upper excitation is 5.05 volts, our upper limit of 5.33 volts is probably too high. Additional proof of this would be secured if photographic observations of the 3900A region of a comet, at small distance from the sun, failed to show the silicon line, 3905.5, whose

TABLE IV

PREDICTED COMETARY SPECTRUM AT SMALL HELIOCENTRIC DISTANCES

El.	Atomic Abundance Meteorites Stone	Iron	B.P. °C.	Excitation Potential Upper	Lower	λ	Int.	Temp. Class	Multiplet.		
O	55.47	..	−183†	—	—	—	—	—	Lowest lines accessible, 12 volts		
Si	15.57	..	3500‡	5.05	1.89	3905.5	10	—	$a^5S - ?$	See footnote 31.	
Fe	11.82	90.5	2450†	3.21	0.00	3859.9	300*R*	I	$1^5D - 1^5D'$	3824—3930	
				3.28	0.94	5269.5	60	I	$1^5F - 1^5D'$	5269—5507	5 strongest of these lines in comets
				3.93	1.54	5167.5	40	II	$1^5F - 1^5D'$	5168—5341	
				4.36	1.54	4383.6	45	II	$1^5F - 1^5G'$	4230—4415	
				4.60	1.54	4045.8	60*r*	II	$1^5F - 2^5F'$	3969—4144	
Mg	10.41	..	1120†	5.05	2.67	5183.7	125	II	$1^3P - 1^3S$	5167—5184	
S	2.63	0.07	444†	—	—	—	—	—	Lowest lines accessible, 9 volts		
Ni	1.02	8.07	2340†	3.53	0.42	3973.5	25	II	$a^1D - a^3P$	3831—3973	
				3.63	1.67	6256.5	15	I	$b^1D - a^3P$	6256—6643	
				3.88	1.93	6314.6	15	II	$a^3P' - a^1D'$	6315—6364	
				4.08	1.82	5476.9	50	I	$a^1S - a^1P$	Comet line, 5474	
Na	0.86	..	877†	2.20	0.00	5895.9	10*R*	—	$1^2S - 1^2P$	5890—5896	*D* lines in comets
				4.09	2.09	6160.7	8*r*	—	$1^2P - 3^2S$	6154—6160	
				4.26	2.09	5688.2	10	—	$1^2P - 3^2D$	5683—5688	
Al	0.58	..	1800††	3.21	0.00	3961.5	10*R*	—	$1^2P - 1^2S$	3944—3962	
Ca	0.42	..	1174††	2.82	0.00	4226.7	500*R*	I	$1^1S - 1^1P$	4226.7	
				3.88	1.88	6162.2	150	II	$1^3P - 1^3S$	6103—6162	
				4.45	2.53	6439.1	150	II	$1^3D - 1^3F''$	6439—6509	
				4.65	1.88	4454.8	80	I	$1^3P - 2^3D$	4425—4457	
				4.75	1.88	4302.5	60*r*	I	$1^3P - 1^3P'$	4283—4319	
Co	*	0.56	2375†	3.49	0.41	4020.9	20	I	$1^4F' - 1^4F''$	3952—4076	
				3.53	1.61	6450.2	80	I	$1^4P - 1^4D$	6093—6450	
				3.54	0.41	3876.8	20	I	$1^4F' - 1^4G$	3808—3979	
				3.87	1.61	5483.3	40	I	$1^4P - 1^4D'$	5230—5483	
K	0.18	..	762†	1.60	0.00	7699.0	10*R*	—	$1^2S - 1^2P$	7665—7699	
				3.06	0.00	4044.1	8*R*	—	$1^2S - 2^2P$	4044—4047	
				3.73	1.61	5832.3	7*R*	—	$1^2P - 4^2D$	5813—5832	
				3.74	1.61	5802.2	6*R*	—	$1^2P - 4^2S$	5783—5802	
Cr	0.16	0.01	2200†	2.90	0.00	4254.3	500*R*	II	$1^7S - 1^7P$	4254—4290	
				3.26	0.98	5409.8	100	I	$1^5D - 1^5D$	5248—5410	
				3.31	0.94	5208.4	300*r*	II	$1^5S - 1^5P$	5204—5208	Appears as a double line in comets
				3.82	0.98	4351.8	60	I	$1^5D - 1^5F$	4338—4412	
P	0.16	0.31	281†	—	—	—	—	—	Lowest lines in the ultra-violet		
Mn	0.11	..	1900†	3.07	0.00	4030.8	200*R*	I	$1^6S - 1^6P$	4031—4034	
				4.89	2.29	4754.0	50	I	$1^4P - 1^4S$	4754—4824	
				5.22	2.16	4041.4	50*r*	I	$1^6D - 1^6D'$	4018—4084	
C	..	0.14	3917†	—	—	—	—	—	Lowest lines in the far ultraviolet		
Cu	..	0.02	2310†	—	—	—	—	—	Lowest lines accessible, 6 volts		

*Entry included with nickel, in stone meteorites

Boiling points from †Landolt and Bornstein, 5th edition, vol. 1, 1923, 313

" " " ‡Kaye and Laby 1921, p. 52

" " " ††International Critical Tables, vol. 3, 1928, p. 204

upper excitation potential Russell[31] gives as 5.05 volts. When the comet comes within one-tenth of a unit, the distance at which Copeland and Lohse[32] found the metallic lines in comet 1882b, we should expect lines of still higher excitation than the ones so far observed. Much better data are available in the photographic region than in the visual, as a comet which showed the 5269 iron multiplet should show much more strongly the ultimate multiplet 3824-3930A. If our identification of chromium is correct the ultimate multiplet at 4254-4290A should also be found. Photographic observations of comets at small heliocentric distances are, of course, very difficult to secure, on account of the daylight conditions under which the observations must be made.

V. Nature and Pressures of Cometary Atmospheres

In order to interpret the observed curves in terms of actual variations of the physical conditions in the comet, it is necessary to translate the estimated intensities into an actual intensity scale. This must, of course, be very rough, and will indicate merely the order of the changes in the spectrum. A considerable part of the data depends on photographic observations. Over the greater part of a photographic blackening curve the density of the image varies directly as the logarithm of the intensity of the incident light. Baxandall, Carroll, and Stratton[33] have found that their eye estimates of the strength of the emission lines on photographs of the iron spectrum are approximately proportional to the logarithms of the true intensities, and correspond to the theoretical intensities if the base 2 is used in the logarithms. The remainder of our observations depend on visual estimates, which are almost certainly on a logarithmic scale. We have decided to consider all the observations as logarithmic intensities, and have arbitrarily taken them as representing magnitudes.

Of the several observed curves, that of sodium appears to lend itself most readily to physical interpretation. It is the best observed, as the D lines occur in a region of great visual sensitivity and are far enough into the red to be fairly free from atmospheric absorption. The curve is sharply defined at its lower end, where it just appears at a distance of 0.8 units from the sun. This point is based on a

large number of composite observations, and hence embodies a representative average. Sodium has the further advantage that its physical properties are well known. The vapour pressure as a function of temperature, and the dissociation heat of the sodium molecule, have been well determined. The D lines are the resonance lines of the neutral atom, and the ionisation potential of the atom is known. For these reasons we shall first discuss the behaviour of the comet in terms of the observed intensities of the D lines.

It is possible to translate the intensity curve for sodium into a curve giving the number of neutral atoms present at any distance from the sun. This follows from a consideration of the total D light emitted by a particular comet. Halley's comet, 1909c, is suitable for the purpose. The D lines appeared at a heliocentric distance of 0.65 units as the comet approached the sun, and vanished again at the same distance as it receded. We assume that for detectability there must be an emission of intensity 0.1 of the background superposed on the continuous spectrum. The presence of very definite Fraunhofer lines leads to the supposition that the energy distribution in the background of the comet was not very different from that of the sun. In this case the energy at 5896 is not far from the average energy in the visual region, and with sufficient accuracy, we may take the limit of detectability of the sodium lines as $0.1\ \Delta\lambda/\lambda_1-\lambda_2$ of the visual energy, where $\Delta\lambda$ is the total width of the D lines, and $\lambda_1-\lambda_2$ the visual range of wave length. Taking the widths as one Angstrom unit, and the visual range as 3000A, the D lines, to be detected, must contribute 6.67×10^{-5} of the visual light of the comet. The visual magnitude of the comet at a heliocentric distance of 0.65 units, corrected to the standard distance of one unit from the earth, was found by Holetschek[34] as $2.^m8$. As the visual magnitude of the sun is -26.7, the comet was $29.^m5$ fainter than the sun. Taking the sun as a black body of temperature 6000°K, Ives[35] has found the luminous efficiency of the sun to be 0.1353. Its total radiation is 3.780×10^{33} ergs per second. Thus the comet emits, in the visual region, $10^{-11.8}\times3.780\times10^{33}\times0.1353$ ergs per second, and to be detected, the D lines must emit 6.67×10^{-5} of this, that is 5.41×10^{16} ergs per second. As the energy of one D transition is given by $E=hc/\lambda$, or 3.33×10^{-12} ergs, the least number of transitions detectable is 1.62×10^{28} per second.

The number of neutral atoms present follows if we know the time it takes for an atom to complete a cycle, that is, to absorb and re-emit a D line. The method is the same as that used by Milne,[36] except that instead of having equilibrium between the gravitational and radiational forces, in this case the former is μ times the latter, so that

$$\mu\{mg(\tau+\tau')\} = (1-w)\, h\nu/c$$

where m is the mass of the atom, g the gravitational force of the sun at the distance considered, τ and τ' the average times the atom spends in the excited and unexcited states, w the dilution factor, and h, ν and c have their usual meanings. Baade and Pauli[37] have determined the value of μ as being

$$\mu = \frac{8\pi^2 e_0^2 h}{m_0 m\, c\, G\, \lambda^3} e^{-\frac{hc}{k\lambda T}}$$

where e_0 and m_0 are respectively the charge and mass of the electron, m the mass of the atom or molecule considered, G the gravitational constant, k the Boltzmann factor, T the temperature of the exciting source, and λ the wave length of the ultimate line of the atom. Substituting the numerical values for the physical constants, we obtain

$$\mu = 9.69\times10^{-8}\frac{1}{M\lambda^3} e^{-\frac{1.430}{\lambda T}}$$

where M is the molecular or atomic weight. In the case of sodium, μ is equal to 473.6. Using the value of g found for the sun, and a distance of 0.65 units, the average time of completing a cycle is found to be 4.39×10^{-3} seconds. The 1.62×10^{28} transitions per second may thus be attributed to 7.10×10^{25} atoms of neutral sodium. As the mass of the sodium atom is $23\times1.66\times10^{-24}$ grams, the total mass of neutral sodium required to emit the observed D lines is 2700 grams. This is probably less than 10^{-15} or even 10^{-20} of the comet's mass, and hence not excessive.

It is interesting at this point to notice that $\tau+\tau'$ varies as $1/g$, and hence as r^2, where r is the heliocentric distance. Thus the number of emissions of the D lines by one atom will increase as $1/r^2$. If this intensity is measured with respect to a reflected back-

ground which varies in strength in about the same way, for a constant number of atoms the contrast will be independent of the distance from the sun. In other words, the observed intensity curve is equivalent to a curve giving the number of atoms present at any distance.

The number of atoms in the head of Halley's comet may be expressed as a density, for the diameter has been determined by Holetschek as 13.3 times that of the earth.[28] The volume is then 2.56×10^{30} cc, and the resulting density is 2.78×10^{-5} neutral sodium atoms per cc. This estimate regards the atoms as producing the D lines only, and would have to be increased somewhat to allow for the remaining members of the series. The difference is probably very small, as not only are such transitions normally less probable, but also they lie in the violet, where the exciting solar radiation is much less intense.

The observed curve gives the change in the number of sodium atoms present in the comet head, and hence should furnish some idea of the physical changes which take place as the comet approaches the sun. Non-spectroscopic considerations have already supplied a considerable amount of data on the nature of the heads of comets. Comets are probably swarms of meteoric stones, of unknown size, held together by their mutual gravitation. The similarity of the metallic spectra observed in comets and that predicted from the known chemical composition of meteorites, as discussed in the fourth section of this paper, strengthens the identification of the stones of the comet heads with meteoric stones. Photometric and gravitational methods of investigation show that the mass of the average comet is very small, of the order of less than one one millionth the mass of the earth. The corresponding density is of the order of 6×10^{-9} gm/cm^3. If the greater part of the mass of the comet is concentrated into the stones, these must be scattered very sparsely through the space occupied by the head of the comet, and the density of the gases between the stones must be very much lower. This is consistent with the high transparency of comets.

The physical interpretation of the observed change in the spectrum with heliocentric distance is difficult. Because of the low mass of the comet the velocity of escape of the atmosphere must be very low, so that there is probably a constant streaming of the molecules

or atoms from the center outwards. A further large mass of material is being lost through the repulsive force of the radiation of the sun. These two factors tend to disturb equilibrium conditions to such an extent as to make equilibrium formulae of very doubtful applicability. For this reason it is interesting to examine the behaviour of a cometary model without assuming thermodynamic equilibrium, as well as one based on the regular formulae.

As a first model, let us consider a surface of sodium, moving through free space toward the sun, under the force of gravitation. The temperature is taken as that of a black body subjected to solar radiation, and is hence equal to $277/\sqrt{r}$ in degrees K, where r is the heliocentric distance.[39] As the body approaches the sun the temperature rises, and more of the metal becomes vaporised. The relation between vapour pressure and temperature for sodium in equilibrium with its vapour is given by the formulae,[40]

$$\log_{10} p = -52.23\ K/T + B \text{ or } p = 10^{-A/T+B}$$

where p is the pressure in mm. of mercury, T the temperature, and $K = 103.3$, and $B = 7.533$ are two empirical constants.

The difference between an equilibrium model and our free space model is that in the latter the molecules do not return to the sodium surface in any appreciable numbers. As a result, the process resembles a continuous effusion from an opening in an enclosure, in which the pressure is equal to the equilibrium vapour pressure. The mass escaping in unit time, from unit surface is given by Jeans[4] as

$$\Delta m = \rho \sqrt{\frac{RT}{2\pi m}}$$

where ρ is the density of the gas, R the gas constant, and m the mass of the molecule. The density ρ is a function of the pressure and temperature, given by the ordinary gas equations

$$p = 1/3\ \rho\ C^2, \text{ and } RT/m = 1/3\ C^2.$$

Substituting the value of p in terms of the temperature, and of T in terms of the heliocentric distance r, the equation for the loss of mass by effusion becomes

$$\Delta m = \sqrt{\frac{m\sqrt{r}}{2\pi R \,.\, 277}}\ 10^{-A\sqrt{r}/277+B}$$

$$= K_1 r^{\frac{1}{4}} 10^{-A\sqrt{r}/277}$$

This formula gives the mass of sodium thrown into the atmosphere of the comet in unit time. As the dissociation potential of molecular sodium[42] is approximately one volt, the sodium will almost immediately become atomic; in fact, on account of the low pressure it is mostly ionised. There are two possible methods of losing the neutral sodium atoms given off. They may be driven off by radiation pressure, or they may become ineffective by reason of ionisation. Probably the first of these causes is usually negligible. This is further brought out by consideration of the ionisation losses. If the ionisation, and the excitation of the D lines, are both due directly to absorption of solar light, the chance of an atom emitting the *D* lines is a definite number of times that of it absorbing sufficient energy to be ionised. As the average duration of a D cycle is, as determined above, 2×10^{-3} seconds, the average duration in the neutral state, while much greater, will not be long enough to allow an appreciable number of neutral atoms to escape by radiation pressure, compared to those lost by ionisation. Thus a constant, representing the ratio of the probability of absorption of the D lines to that of ionisation of the atoms, multiplied by the number of atoms being produced as determined from the equation for Δm, gives the number of D emissions per unit time, at a distance r from the sun. The number of such transitions produced per unit area of sodium surface, is then given by

$$\Delta n = K_2 r^{\frac{1}{2}} 10^{-A\sqrt{r}/277}$$

where the constant K_2 involves the unknown ratio of the emission and ionisation probabilities. To compare this with the observed curve, giving the change of intensity of the *D* lines with r, it must be multiplied by the contrast factor varying as r^2, whence

$$I = K_3 r^{9/4} 10^{-A\sqrt{r}/277}$$

$$\text{or } \log_{10} I = C + \frac{9}{4} \log r - A\sqrt{r}/277.$$

Figure 5 and the following table show the variation of $\log I$ with r, compared with the observed intensities transferred to the base 10.

r	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
$\log I$	9.23	7.35	5.78	4.42	3.18	2.05	0.99	0.00
$\log I_{obs}$	1.60	1.32	1.03	0.74	0.47	0.20	0.05	0.00

It is immediately obvious that the intensities, as predicted from this model, increase much more rapidly than do the observed intensities. We have not, then, effusive equilibrium. If the model here discussed is to represent the observations, it might be modified by considering an exhaustible, rather than a limitless, supply of

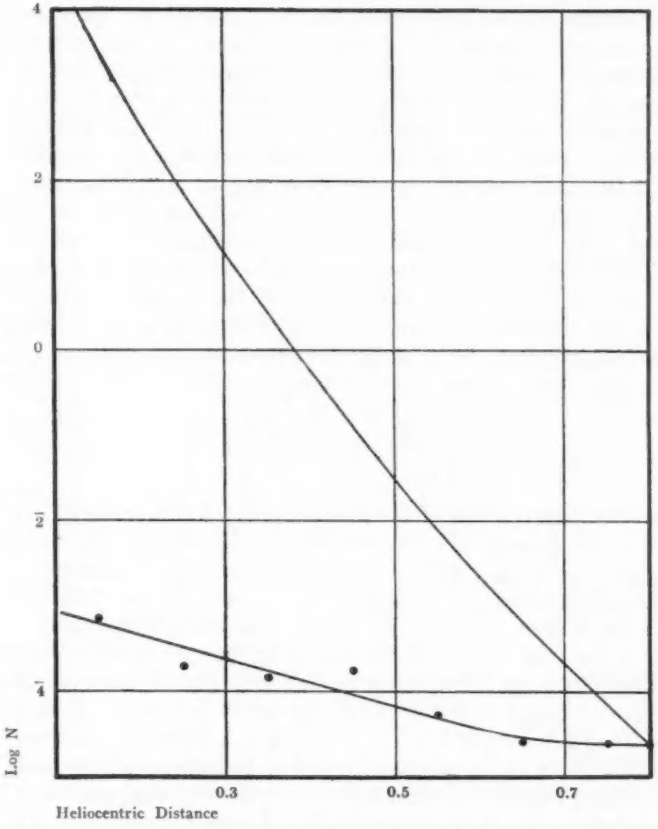

Figure 5.—The lower curve gives the observed number of neutral sodium atoms; the upper one, the number computed from a model in effusive equilibrium. Ordinates are logarithms of the number of atoms; abscissae are heliocentric distances.

sodium present. In other words, the sodium may be scattered throughout the stones of the comet head, in such a way that only a relatively small amount is exposed at one time. Some idea of the effective area actually exposed could be derived, if the physical constants relating the probability of ionisation to the probability of excitation were determined for the D lines. It must also be remembered that the loss by radiation pressure has been neglected, though this could not introduce a correction of the order of the observed, 10^{-7}. It is difficult to conceive of an error in the scale of observed intensities which could account for the discrepancy. Probably, therefore, the lack of sodium surface is the explanation.

It is interesting to compare these results with those obtained from a model in which an atmosphere of sodium vapour, in equilibrium with the solar radiation, is kept at such a pressure as to give the observed number of neutral atoms. As the density of the neutral sodium at $r=0.65$ units was found to be 2.78×10^{-5} atoms per cm³, the observed intensity curve is reduced to atomic densities. The Saha formula for a single gas, using the gas pressure rather than the electronic pressure, and introducing the dilution factor, becomes

$$\log \frac{x^2}{1-x^2} = -\frac{5048I}{T_0} + \frac{5}{2} \log T_0 - 6.5 - \log p_{atm} + \log w$$

where x is the fraction of the atoms ionised, I the ionisation potential of the element, T_0 the temperature of the exciting source in degrees Kelvin, p_{atm} the pressure of the gas in atmospheres, and w the dilution factor. The number of atoms present in a unit volume of a gas is given by $N=p/kT$, where k is the Boltzman constant, and T the temperature of the gas. The number of neutral atoms is then $N(1-x)$. By comparing this with the observed numbers, the pressure may be deducted. In the case of sodium, I is 5.12 volts, and T, as before, is $277/\sqrt{r}$. T_0 is taken a 6000°, and $w=a^2/4r^2$, where a is the radius of the sun, and r the heliocentric distance of the comet, both in astronomical units. The resulting pressures are given below, and shown graphically in Figure 6.

r	0.15	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
log N_{obs}	$\bar{4}.82$	$\bar{4}.68$	$\bar{4}.39$	$\bar{4}.10$	$\bar{5}.83$	$\bar{5}.56$	$\bar{5}.46$	$\bar{5}.41$	$\bar{5}.37$
log p	$\overline{14}.57$	$\overline{14}.34$	$\overline{15}.97$	$\overline{15}.67$	$\overline{15}.41$	$\overline{15}.18$	$\overline{15}.04$	$\overline{16}.95$	$\overline{16}.86$

Thus for the equilibrium model, a range of pressures of about one hundred is all that is required to give the observed curve. Such an increase in pressure, as the comet goes in from 0.9 to 0.15 units of heliocentric distance, would seem to be quite possible, considering the rise in temperature of the stones and gases, the increase in vaporisation and the general contraction of the head on approaching perihelion.

Using the same equilibrium model, the pressure and change of

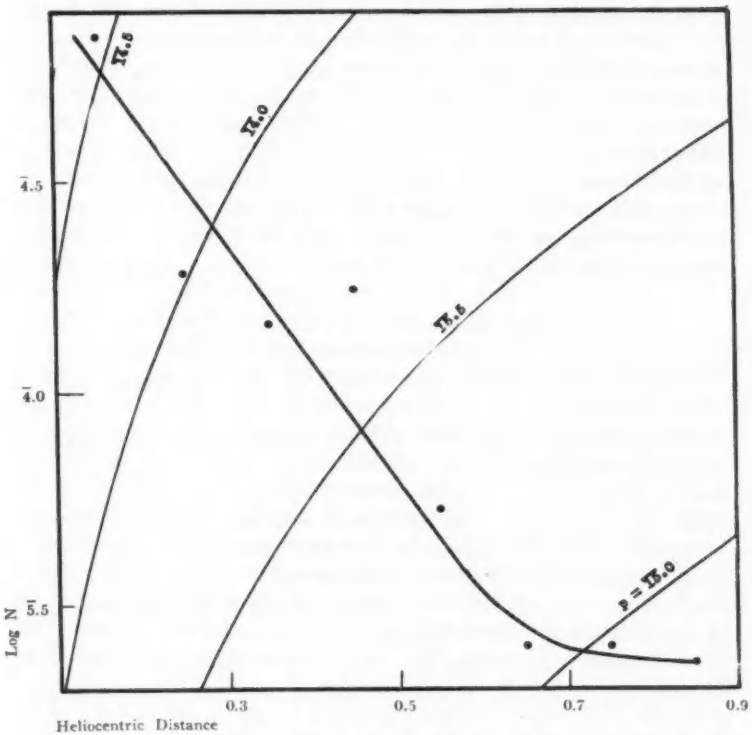

Figure 6.—The relation between logarithm of the number of atoms of sodium (ordinate) and heliocentric distance of the comet (abscissa), on the assumption of thermodynamic equilibrium. The dots and heavy line represent the observed relation; the lighter lines are lines of equal pressure.

pressure required to satisfy the observed intensity curve of the cyanogen bands may be determined. This is a much less definite process, as the exact source of the *CN* molecules, and the energy required for their production, are unknown. C_2N_2 usually dissociates at a very low voltage, about two volts, into carbon and nitrogen, rather than into $2(CN)$. The process is probably much more complicated than our formulae assume. We shall suppose that the same number of transitions is required to produce a given intensity of the cyanogen band, as of the D lines of sodium. In the case of cyanogen, consider the *CN* (3883) band. Baade and Pauli's formulae for the ratio of radiational to gravitational pressure, as given above, gives 137 as the value of μ for cyanogen. The molecular weight is taken as 26, the solar temperature as 6000° K, and the resonance wave length as 3883A. There must thus be 473.6/137 times as many neutral *CN* molecules as sodium atoms present to give the same intensity. This, for as sodium, does not take account of the other radiations produced by the neutral carrier. For sodium they were of a much lower intensity than the *D* lines, but for cyanogen the other bands are of comparable intensity. An estimate of the relative contributions of the various heads is difficult; *CN* (3883) is much brighter but rather more concentrated than the other four heads. As an estimate we shall assume that one fifth of the neutral molecules contribute to the intensity of the subhead *CN* (3883). This estimate may alter the pressure determination, but not the pressure changes as dependent on heliocentric distance. Then to produce an intensity equal to that found in the *D* lines, we require $(473.6/137)\times 5$ times as many molecules, and the pressures may be determined from the Saha formula to give this number of neutral molecules. The value of *I*, the ionisation potential, is the dissociation energy of the molecule, determined by Birge[43] as 9 5 volts. Below are given, for different heliocentric distances, the number of molecules from the observed curve, and the deduced pressure. The small change in pressure with distance is even more marked than for sodium.

r	0.1	0.3	0.5	0.7	1.0	1.5	2.0	2.5
log N_{obs}	$\bar{4}.65$	$\bar{3}.85$	$\bar{3}.91$	$\bar{3}.93$	$\bar{3}.93$	$\bar{3}.90$	$\bar{3}.65$	$\bar{3}.21$
log p	$\overline{16}.86$	$\overline{16}.86$	$\overline{16}.61$	$\overline{16}.44$	$\overline{16}.24$	$\overline{16}.02$	$\overline{17}.73$	$\overline{17}.38$

The carrier of the Raffety bands is unknown, and but few of the

bands have been analyzed. As a result the dissociation potential is unknown. From their early disappearance on approaching the sun it would appear that the substance must be very volatile, and have a dissociation energy considerably lower than that of the C_2 molecule which gives rise to the Swan bands, 7.0 volts. The potential of the Raffety carrier is probably lower even than that of sodium, 5.12 volts.

It is probable that neither of these two models represents the actual cometary conditions. The first model assumes a constant streaming of the molecules and atoms away from the stones of the comet head, with ionisation losses dependent directly and entirely on solar excitation. In such streaming, collisions would be rare. The second model, in which streaming losses are neglected and equilibrium conditions are assumed, must certainly be only a poor approximation. A combination of the two models is probably a much better representation of the cometary conditions. The question as to the relative importance of the two methods of loss of atmosphere is rather difficult, and a great deal of accurate spectrophotometry is desirable before quantitative work is of much use.

VI. Future Observations of Cometary Spectra

Examination of all the spectral and many of the photometric observations of the past reveals the fact that a great number of them are practically useless, in that they have been made without any definite systematic basis, and as scattered observations rather than as a regular program. Interpretation of such work is very difficult, and combinations of such observations rather ineffective.

The aim of a spectrophotometric observation should be to obtain, with as much resolving power as the brightness of the object will allow, a curve which will give the absolute energy as a function of wave length, over as long a range of the spectrum as is possible. Such an observation is, of course, far better than photometry in the ordinary, non-monochromatic sense of the word. A series of such ideal observations, for a sufficient number of comets, and over a large range of heliocentric distance, would settle many questions. One of the most important is that of the variation of the brightness of a comet on approaching perihelion. As mentioned above, comets

do not vary, in *integrated* brightness, according to any definite law. The light of some comets varies as r^{-3}, of others by as much as r^{-6}, while simple reflection of solar light would lead to the expectation of a law of r^{-2}. The question is then whether the observed increase in total brightness is explicable as a relative increase in the gaseous emission spectra with increasing temperature and excitation, or whether, owing to an increase in the number of dust particles given off by the cometary stones, the power of the comet to reflect sunlight is really abnormally increased. In other words, the absolute strength of the continuous spectrum should be expressed as a function of the heliocentric distance. Further work on the continuous spectrum should include an examination of the distribution of the energy as a function of wave length, in order to detect and measure departures from solar distribution such as Bobrovnikoff's[44] violet type spectrum. Absolute photometric measures of the intensities of the emission lines and bands would serve to measure the number of transitions of each kind present, and hence give quantitative data on the relative abundances of the various states of the substances present, and the general physical conditions.

The securing of such spectroscopic data is difficult, because of the faint, diffuse nature of comets. One of the most satisfactory methods is probably offered by the use of an objective prism. The focal length of the camera should be very short, the necessary dispersion being secured by means of wide angle prisms. The lens should be of short focal length, in order to reduce the image of the comet as much as possible, and of large aperture and wide field, in order that a sufficient range of comparison stars, of determinable energy distribution, may be photographed during the exposure on the comet. The plates should be exposed to a sensitometer immediately before or after the exposure on the comet. The gradient of the plates at different wave lengths is then determinable from the sensitometer patches, and the reference points may be taken from the stars of measured energy distribution.

As well as these photometric results, certain wave length problems remain to be solved by means of slit spectroscope observations. Slit spectra of the comets should be made, with solar or sky spectra for comparison made under the same conditions and on the same plate, in order more definitely to settle the identification

of the unknown lines in the photographic region with continuous regions of the solar spectrum. In the rare case of a large bright comet coming very close to the sun, there is much to be done, in checking the iron, nickel, and chromium lines of the comet of 1882, and in extending the wave lengths observed into the extreme red, for such lines as *Co* at 6450, and *K* at 7699 and 7665; and into the violet, for the iron lines at 3900, the 4227 line of *Ca*, the 4254 lines of *Cr*, and the 4031 line of *Mn*. As mentioned above, the work in the violet is difficult, because at small distances from the sun the comet must be observed in daylight and hence, unless the comet is very bright, it cannot be photographed against the blue sky light. A further problem for a slit spectroscope is the securing of plates of the spectrum of the tail, in order to measure the radial velocity shifts due to the motion under radiation pressure. This is possible only for the bright comets, but it has important bearing on the general problem of the physical conditions in the comet.

The writer is greatly indebted to Mr. H. H. Plaskett for suggestions and discussion throughout the work.

VII. Summary

During the past sixty-four years 830 spectroscopic observations of ninety-four comets have been published in 410 reference papers.

The wave lengths, intensities, occurrence and identifications of the emission lines and band heads are tabulated. The unknown lines in the photographic region have been identified with the narrow conspicuous regions of the spectrum of reflected sunlight; such regions owe their prominence to their internal freedom from strong Fraunhofer lines, and to the strong Fraunhofer lines which border them. Only nine lines remain unidentified; these all lie in the visual region, and appear only when the comet is very near the sun.

The relation between the heliocentric distance and the mean intensity of the prominent bands and lines has been found. The emissions so examined are the Swan bands, C_2 (5635, 5165, 4737, 4381), cyanogen, *CN* (4216, 3883), the Raffety bands, CH_x (4108), and the D lines of sodium (5893). The band systems reach maxima at from one to two units from the sun, while the D lines are evidently maxima at the sun, and absent beyond eight tenths.

A comparison between the spectra of comets and the low-excitation spectra of meteoric elements shows that the identified lines (*Na*, *Fe*, *Ni*, and *Cr*) are the ones which would be predicted from the assumption that cometary heads are composed of meteoric stones. The limiting excitation potential of the upper level of a transition in an atom in a comet head is evidently less than five volts.

Interpretation of the observed curves suggests that the atmosphere of the comet is not in effusive equilibrium. An assumption of thermodynamic equilibrium indicates that the effective partial pressure is of the order of 10^{-14} *atm* when the comet is one tenth of a unit from the sun, and decreases to 10^{-16} *atm* when the comet reaches one unit distance.

The problems and suggested methods of spectroscopic observation of future comets are outlined.

REFERENCES

[1]Donati, *A.N.* Vol. 62, p. 378 (1864).
[2]Baldet, *Ann. de l'Obs. d'Ast. Phys. de Paris*, Vol. 7, p. 65 (1926).
[3]Valentiner, *Handwörterbuch der Astronomie*, Vol. 4, p. 231 (1902).
[4]Copeland and Lohse, *Copernicus*, Vol. 2, p. 234 (1882).
[5]Thollon and Gouy, *Comptes Rendus*, Vol. 96, p. 371 (1882).
[6]Albrecht, *L.O.B.*, Vol. 5, p. 183 (1910).
[7]Rosenberg, *Ap. J.*, Vol. 30, p. 267 (1908).
[8]Bobrovnikoff, *Ap. J.*, Vol. 66, p. 439 (1927).
[9]Fowler, *Series in Line Spectra*, p. 4 (1922).
[10]Baldet, *Ann. de l'Obs. d'Ast. Phys. de Paris*, Vol. 7, p. 108 (1926).
[11]Raffety, *Phil. Mag.*, Vol. 32, p. 555 (1916).
[12]Baldet, *Ann. de l'Obs. d'Ast. Phys. de Paris*, Vol. 7, p. 103 (1926).
[13]Copeland and Lohse, *Copernicus*, Vol. 2, p. 234 (1882).
[14]Orlov, *Russian Astronomical Journal*, Vol. 4, p. 1 (1927).
[15]Campbell, *Ap. J.*, Vol. 27, p. 230 (1908).
[16]Huggins, *Atlas of Representative Stellar Spectra* (1899).
[17]Bobrovnikoff, *Ap. J.*, Vol. 66, p. 439 (1927).
[18]Holetschek, *Denkschr. d. Akad. d. Wissn, Math.-natw Kl Wien*, Vols. 63, 77, 88, 93, 94.
[19]Van Biesbroeck, *A.J.*, Vol. 36, p. 43 (1924).
[20]Hind, *The Comets* (1852).
[21]Mascart, *La Comète de Halley* (1910).
[22]Pretty, *Proc. Phys. Soc.*, Vol. 40, p. 71 (1928).

[23]Christy and Birge, *Nature*, Vol. 122, p. 205 (1928).
[24]Birge, *Private Letter*, Mulliken, *Phys. Rev.*, Vol. 32, p. 206 (1928).
[25]Zanstra, *Phys. Rev.*, Vol. 28, p. 428 (1926).
[26]Payne and Shapley, *Harv. Obs. Circ.* 317 (1928).
[27]Russell, *Ap. J.*, Vol. 61, p. 223 (1925).
[28]Bechert and Sommer, *Ann. d. Phys.*, Vol. 77, p. 351 (1925); Vol. 77, p. 537 (1925).
[29]Shenstone, *Phys. Rev.*, Vol. 28, p. 449 (1926).
[30]Catalan and Bechert, *Zeit. f. Phys.*, Vol. 32, p. 336 (1925).
[31]Russell, Unpublished data, kindly communicated by letter.
[32]Copeland and Lohse, *Copernicus*, Vol. 2, p. 234 (1882).
[33]Baxandall, Carroll, and Stratton, *M.N.R.A.S.*, Vol. 87, p. 472 (1927).
[34]Holetschek, *Denkschr. d. Akad. d. Wissn., Math.-natw. Kl. Wien*, Vol. 93, p. 219 (1915).
[35]Ives, *J.O.S.A.*, Vol. 12, p. 77 (1926).
[36]Milne, *M.N.R.A.S.*, Vol. 84, p. 354 (1924).
[37]Baade and Pauli, *Naturwiss.*, Vol. 15, p. 50 (1927).
[38]Holetschek, *Denkschr. d. Akad. d. Wissn., Math.-natw. Kl. Wien*, Vol. 93, p. 222 (1915).
[39]Russell, Dugan and Stewart, *Astronomy*, Vol. 2, p. 540 (1927).
[40]*International Critical Tables*, Vol. 3, p. 204 (1928).
[41]Jeans, *The Dynamical Theory of Gases*, p. 121 (1925).
[42]Loomis, *Phys. Rev.*, Vol. 31, p. 329 (1928).
[43]Birge, private letter.
[44]Bobrovnikoff, *Ap. J.*, Vol. 66, p. 439 (1927).

AN "AUTOCOMPARATOR"

By William H. Christie

The following is a short description of what is, I believe, a measuring instrument embodying a totally new principle. The instrument is based on the well-known Hartmann Spectrocomparator, but its originality lies in the fact that it utilizes, not a standard spectrum for comparison, but the spectrum under measurement itself.

Although it is primarily intended for the measurement of stellar spectra, the "Autocomparator" (if I may so term it) may be modified for use in several other lines of research.

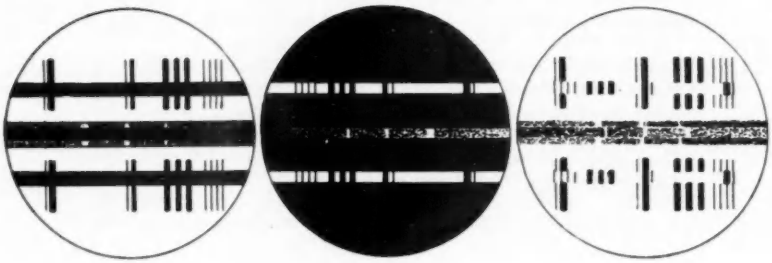

Fig. 1. Images as seen in the "Autocomparator".

The principle of the instrument is simply as follows: The converging beam of light from a microscope objective is divided into two parts, of equal intensity, by a half-silvered plane-parallel glass plate placed at an angle to the optical axis of the objective. One of these beams is reversed by a lens, or system of lenses, while the other is unaffected; these two beams are then re-united, forming an image in the focal plane of a positive eyepiece.

If, now, the central strip of an image of a spectrum formed by one of the beams is cut off, and the remaining portion of the other image obscured, we will see an image with the eyepiece which is composed partly of the unaffected beam and partly of the reversed

beam. On moving the spectrum under the objective from left to right the image formed by the unaffected beam will move from right to left, whereas that formed by the other will move from left to right.

By using a partly silvered glass diaphragm (as used in the Hartmann Spectrocomparator) strips of the images of both star and comparison spectra, formed by one of the beams, may be made

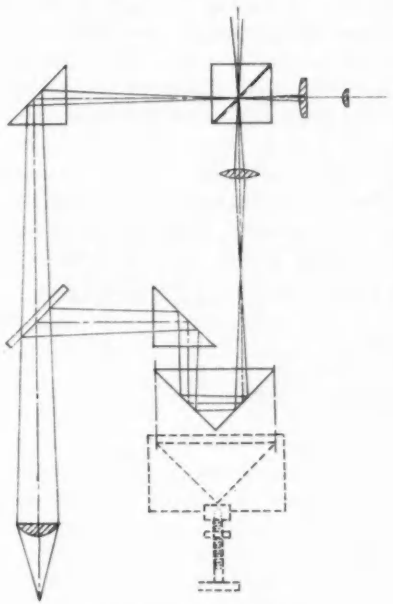

Fig. 2. Optical Train.

to lie between the images formed by the other beam. This is made clear in Fig. 1. In *A* we have the image of a spectrum formed by, let us say, the unaffected beam, as it would appear were the light from the other cut off; in *B* we have the image formed by the other beam with the light from the former cut off; while in *C* we have the two images superimposed.

If one of the images of a comparison line is now made to coincide

with the other image of itself the corresponding star line—if there be one—will show a displacement with respect to the other image of itself, unless it be of exactly the same wavelength as that of the comparison spectrum, *and the displacement will be exactly double that which actually exists.*

The method of measurement with such an instrument would be identical with that of the ordinary micrometer, save that, instead of bisecting the lines with a cross wire, they would be matched against themselves. This should be of great advantage in measuring broad diffuse lines and those that are unsymmetrical, while there is nothing to be lost with the sharper lines, but perhaps something to be gained by the double displacement, which should approximately double the accuracy with which a setting can be made.

The optical train of the "autocomparator" is shown schematically in Fig. 2, which is self-explanatory. It should be noted that the double reflection prism may be adjusted so as to bring the reversed beam to the same focus as the unaffected one. The magnification of both beams may be equalized by sliding the reversing lens towards or away from the eyepiece.

Dominion Observatory,
Ottawa.
September, 1928.

RADIO TALKS ON ASTRONOMY, OVER CFCT, VICTORIA, B.C.

By W. E. Harper

XIII. New Observatories (2)

(November 14, 1928)

Since my last talk to you the news has been released of the building of the world's largest telescope, one 200 inches in diameter, at Mount Wilson, California. While aware of the project at the time one could not refer to it until such announcement had been made by those at the head of the undertaking.

Continuing my last talk to you on observatories that have been recently established, I am now going to discuss University observatories in the United States, the equipment in many cases being the gift of wealthy graduates.

At Cornell University there is a 12-inch refractor which is used for instructional purposes as well as for a limited amount of research work on double stars. The graduates of the College of Civil Enginering supplied the funds for the mounting; the lens, and possibly the building, being donated by Fuertes, after whom the telescope is named.

There is sometimes difficulty experienced in getting a suitable site for an observatory that is to be associated with a university. One cannot go too far away from the campus and usually surrounding tall buildings cut out a clear view of the sky. This difficulty was very pronounced in the case of Columbia University, New York, when a new 10-story chemical building blocked their view in one direction and a proposed 13-story physics building threatened to do so in another. Accordingly plans were revised so that the observatory could be placed on top of the 13-story building. Here the 12½-inch telescope and other instruments are mounted. The glare of lights from Broadway, close at hand, does not bother much but the high winds do sway the building and vibrate the telescope, though not nearly so much as had been feared. The section of the roof fifty feet square devoted to observatory work

is surrounded by a parapet and the enclosure is an admirable place for groups of students to make naked-eye observations of the heavenly bodies. Naturally one cannot see as faint stars as are possible away from the city's glare but those down to magnitude 4.5 are readily observed by the unaided eye.

Hitherto there have not been many observatories in the southern states. The University of Virginia with a 26-inch, donated by McCormick about 1881, has been about the sole representative, but now several are contemplated. One of these, opened in 1925, is at Columbia, South Carolina, where a Mr. Henshaw, donated the 15-inch refractor and another man, Mr. Seibels, the building. It will be used both for instruction to students of the University of South Carolina and for research as well.

The Baldwin-Wallace University of Ohio is also planning to have a 15-inch refracting telescope and already a large amount of the $125,000 required has been subscribed.

At the Van Vleck observatory in Middletown, Connecticut, they received and installed in 1922 the 20-inch refractor which had been ordered many years previous. It is to be used in determining the distances of stars.

The foregoing five telescopes are all of the refractor variety with the lens at the outer end of the tube. They range from 12 to 20 inches in diameter. The next four, also connected with universities, are of the reflecting type and are larger.

The University of Kansas is to have a 24-inch reflector, the gift of a prominent business man, Pitt by name. The donor, who is an expert machinist, is to grind the mirror himself. It will be made of pyrex glass which is coming rapidly to the fore for such instruments by reason of its being so slightly affected by changes of temperature.

The University of Illinois has recently put into operation a 30-inch reflector which is intended to be used for variable star work. Certain stars vary in the amount of light they send us and a study of these variations yield us a great deal of information as to their make-up.

The University of Texas has had a large sum of money left it in the will of a certain Mr. McDonald, who died recently. It is said to have come "as a bolt out of the blue" as McDonald had

never hitherto shown any great interest in astronomy. The relatives have tried to have the will set aside but all court actions have failed and the University comes into the possession of $1,125,000 to be devoted to the building and upkeep of a large observatory. A representative had been looking over the observatories of the Pacific Coast but I do not know the exact size decided upon. It will probably be 60 inches at least.

The last university-controlled telescope to be mentioned, and the largest, is that connected with the Ohio Wesleyan University. This is a denominational institution under the control of the Methodist Episcopal Church and they must be rather proud to have the third largest telescope in the world. While not actually completed, the mounting is ready awaiting the disk. It was intended to have a mirror about 60 inches in diameter but as it had, by the terms of the will of the donor, named Perkins, to be all of American manufacture, it was found hard to get bids for its construction at any price.

Finally the Bureau of Standards at Washington was appealed to, to cast the huge disk and after several unsuccessful attempts they finally secured a beautiful piece of glass 70 inches in diameter and 11 inches thick, weighing 3,500 pounds. The story of the making of these big disks is a very fascinating one. The necessary ingredients to make up the glass, and weighing two or three tons, are assembled in a huge fire-pot capable of withstanding high temperatures. It is brought to a temperature of 1350° C., kept at that temperature for a while, then poured into the 70-inch mould and allowed to cool very, very slowly. It was poured on May 7, 1927, and the glass disk taken out on January 16, 1928. It was thus nearly eight months in the cooling process.

Reports say it is a beautiful piece of glass and it should, when ground and polished, be a considerable addition to the observatory equipment of the world.

I wish to say a few words now regarding observatories and similar instruments planned with a view of popularizing astronomy and catering to the needs of the average man of the street.

The First Unitarian Church of Los Angeles, California, has installed on the parish house a six inch telescope with an attendant

in charge. This is available to the public one evening of each week for viewing the interesting objects in the heavens.

The city of Des Moines, Iowa, in 1921 established a municipal observatory, beautiful in design, and having three telescopes, the largest being a 9-inch refractor. It is open two evenings a week when lectures are given and an opportunity afforded to look through the telescopes. Their initiative along such advanced lines of community education is very commendable.

The Chabot observatory of Oakland, California, is somewhat similar though it was donated by Chabot to the community. Here are two telescopes, a splendid one of 20 inches diameter and another of 8 inches. It is open to the public on several evenings each week and classes from the city's schools come for regular instruction. The curriculum of the city's schools include courses of work at the observatory.

During the winter tourist season at Miami, Florida, there is a battery of 5-inch telescopes in operation, donated for the most part, and placed in charge of members of the local astronomical society there. Outstanding astronomers, too, come each year to give addresses which are listened to by audiences of more than a thousand.

The newest development in the line of diffusing a knowledge of the heavens among the rank and file had its origin in Germany. It is the Zeiss Planetarium, and there are about fifteen in Germany and one in Munich. The building is hemispherical in shape and by means of projection apparatus all the naked eye stars appear on the inside of the dome and the appearance is just as if one were looking out upon the sky. The daily and yearly motions of the stars can be shown and the courses of the planets among them. A ray of light under the control of the operator serves to point out objects to which attention is called by the lecturer.

Moscow has copied the idea and the city has appropriated $150,000 for the purpose. Let us not be too severe upon people with such a vision.

Chicago follows suit and Adler of the Sears-Roebuck firm has given $500,000 for the purpose and will also personally supervise its construction. One is also projected for the American Museum of Natural History in New York.

A word might be given in conclusion regarding various endow-

ments, not previously mentioned, that have made possible some of the recent progress in astronomical science. There is the well-known Rockerfeller Foundation and the newer Guggenheim Foundation which last year enabled 75 students to undertake Research work. The Wilson bequest of $150,000 enables Harvard to give advanced courses in astrophysics. The Yarrow Foundation, and local people will readily recognize the name, amounts to $500,000 and is for the purpose of establishing Research Fellowships.

XIV. Astronomy in Everyday Life

(December 12, 1928)

One of the questions most commonly asked an astronomer is,—What is tbe practical value or benefit of the astronomical work in which we are engaged? Among our Saturday evening audiences at the Observatory such a question may usually be expected and indeed, one would feel just a little lonesome if it failed to be raised. To be perfectly honest, though, it does not seem to be asked quite as frequently as in earlier days when the character of the work, in which the staff of the Observatory is engaged, was not so generally understood as now. Moreover, I believe our experience is similar to that of astronomers at other observatories, and it would appear as if it were being realized by the general public that even in this materialistic age, work is being carried on, and rightly so, that has not a vestige of practical material end in view.

But while our own particular research work on the stars has no utilitarian goal in view that does not imply that astronomy is devoid of practical applications. Indeed, some of these have become so woven into our everyday lives and accepted in such a matter of fact way that often their origin is unsuspected. So, in the ten minutes at my disposal to-night I just wish to recall to your minds a few of the practical ways in which astronomy is serving mankind.

(1) It furnishes us with accurate time. How necessary this has become in our busy, bustling world! Think of large manufacturing plants where accurate time becomes very desirable, if not indeed essential, to the efficient working of the same. Think of express trains due to pass one another at certain times and of

the possibilities of collisions if both watches are not standardized and show accurate time.

And what, you ask, has the astronomer to do with accurate time, which we can get from the local jeweller? The astronomer has *everything* to do with it, because he determines it from the stars and then furnishes the jeweller with it. Our earth spinning on an axis from west to east once in 24 hours causes the sun in the daytime and the stars at night to appear to move across the sky from east to west. It is sometimes thought that we use the sun as our time-piece in thus marking off the day but such is not the case, for the sun is exceedingly irregular in its movements. We speak of the time when it crosses our north and south line in the heavens as the time when it transits, or goes across, our meridian. This is called true noon. But the interval between such successive noons is never the same for any two successive days of the year and consequently no timepiece could be constructed that would keep time with the sun. The interval, however, between successive passages across our meridian of any particular star is constant, and astronomers with their transit instruments can record the time of such meridian passages accurately to the hundredth part of a second and, with a little computation, can deduce for us ordinary standard time. Yes, our whole time system throughout the world is dependent upon observations of the stars.

In the Parliament Buildings at Ottawa, and the numerous Departmental Buildings in connection therewith, a system of electric clocks has been gradually developed in which the dials are moved electrically, keeping step, so to speak, with the master clock in the observatory there. Six hundred clocks are thus controlled for the convenience of our legislators and public servants. Moreover, by coupling the master clock to the telegraph lines at a stated time each day, accurate time is rapidly disseminated throughout our land. Time is also broadcast at regular intervals, and please don't forget, when your radio announcer gives you accurate time, that an astronomer has done the "spade work".

(2) Accurate maps of the continents and islands depend upon the astronomical determination of the latitudes and longitudes of their salient features. The boundary lines between nations are often fixed by observations of the stars. The 49th parallel of

latitude between us and our cousins to the south is a case in point, and so accurate are these observations that no uncertainty greater than a few feet exists as to where this imaginary line shall fall. From vantage points in the mountain region the narrow vista that has been cleared to mark the line shows clearly the slight curve resulting from the spherical form of the earth. And not only boundary surveys but field surveys as well call astronomy to their aid. On the great prairie stretches it might be thought that one could chain off section after section without any recourse to astronomy. But such is not the case; the northern edges of each township have to be surveyed slightly less in length than the southern, if the sides are to run due north and south. The amount of this shortening is based upon the known figure of the earth and has to be astronomically determined. In the older parts of Ontario and other eastern provinces there are jogs of a few hundred feet in the north and south roads, as we pass from township to township, due to this failure to call astronomy to the surveyor's aid.

It may be mentioned that it was the need of a station in Canada to serve as a base for such latitude and longitude observations as were necessary in the coordination of surveys that called into existence the Ottawa Observatory.

(3) But useful as astronomical science is for locating our position upon land, it becomes almost indispensable on ocean voyages. Modern discoveries, such as radio, are making us less reliant upon the oldest of the sciences for charting our course at sea but it is still true that from the moment we leave, say, Victoria, until we arrive at Honolulu or Yohokama or Sydney we are guided by astronomical tables prepared long in advance by the astronomer and relating to the positions of the Sun, Moon and stars. His chronometer and engine speed may, with the aid of the compass, tell the captain his approximate position, nevertheless wind and tide may bear him well off the course laid down and he gladly welcomes a sight of the sun or of the stars to determine his accurate position. It was for this very purpose that the Royal Observatory at Greenwich was instituted over 250 years ago, for King Charles was convinced that some such institution to prepare nautical data was necessary if mariners were to sail in safety the wide world over.

To-day each great nation has its own nautical staff and the

information is prepared several years in advance. One computation would suffice for all but international amity has not yet become so manifest that any nation would care to jeopardize its safety by having to depend upon another for such information, though there is co-operation between the different national offices. Nautical data require considerable time to prepare.

(4) And then, too, comes the very essential work of predicting the tides. From the relative positions of the sun and moon, which can be calculated years in advance, one can deduce just what pull each will exert upon the waters of the ocean and what the height of the tide will be at any instant in any of the harbours of the world. Such information is vital not only to ocean-going ships but for local mariners as well.

The foregoing four ways in which astronomy is serving our everyday needs are but samples of many that might be mentioned. We do not dwell upon these practical applications of astronomy to the immediate needs of mankind as they are relatively unimportant when compared with the contribution which the pure knowledge side of astronomy has made to the civilization of the world. If our planet had been one which was blanketed in heavy clouds, preventing us from ever seeing the heavenly bodies, studying their orderly motions, and learning of the immensity of the universe, then civilization to-day would still be in its primitive stage; we would be creatures, groping on the surface of the earth with no thought of things beyond.

And just as Astronomy in the past has stimulated other sciences so is she doing to-day. The stars may be regarded as high temperature laboratories where the astronomer may co-operate with the physicist in studying the behaviour of matter at temperatures unattainable in terrestrial laboratories.

PAPERS PREPARED FOR THE D.A.O. CLUB

COSMIC RADIATION

SEMINAR No. 76

The history of the discovery of this radiation coming to us out of space is quite recent and it is only within the last two or three years that its presence has been demonstrated. However, many earlier experiments leading up to this discovery were performed and may be interesting to note chronologically.

In 1901 C. T. R. Wilson and Geital independently noticed that their electroscopes lost their charge due to some radiation causing the gas in their instruments to become ionized.

The next year McLennan and Burton at Toronto and Rutherford and Cooke at Montreal found that absorbing media would lessen this ionization but not entirely eliminate it.

C. S. Wright, in 1908, made experiments over frozen lakes and in tunnels and found that part, at least, of this ionizing radiation was due to the earth, probably coming from radioactive content in the rocks.

Balloon ascents were made by Gockel, Hess and Kohlhörster in Europe in 1910, which showed that the radiations were not entirely of a terrestial origin.

This brings us to the series of experiments conducted from 1921 to 1927 by Millikan and his colleagues. Balloon, airplane, and mountain peak observations were made. The results showed the existence of radiation of higher frequency than any previously considered and of very high penetrating power. The principal known facts about these rays may be briefly stated.

They appear to have their origin in space, perhaps even beyond the Milky Way, as local conditions have no effect upon them.

They are of extremely short wave-length, about one eight-millionth that of the shortest visible light. They are also very penetrating being able to pierce 6 feet of lead.

The total energy brought to us by them is about one-tenth that of the starlight.

In closing a few of the theories as to the origin of these rays may be quoted; these are

(1) The capture of a high-speed electron by a nucleus would set free a great deal of kinetic energy which might supply that necessary to these rays. It is not unreasonable to presume that both nuclei and fast-moving electrons do exist in space.

(2) The transmutation of atoms may be accompanied by some of the mass being "left-over" and appearing as radiation. Such a change as hydrogen into helium would allow for the production of this radiation.

(3) One of the more speculative hypotheses is that the reverse process, the change of radiation back into mass may be going on and these rays produced at that time. This theory, of course, serves the double purpose of assigning an origin to these rays, and giving us the comforting assurance that the universe is not running down and the energy radiated so lavishly by the sun and stars is not ireevocably lost in the depths of space.

R. M. PETRIE.

THE LIGHT OF THE NIGHT SKY*

SEMINAR NO. 77

The light of the night sky has been studied by various investigators during the past thirty years. Newcomb calculated that its equivalent value was that of approximately 700 stars of zero magnitude, the Milky Way regions contributing per unit area twice as much as non-galactic regions. Similar values were obtained by Burns, Townley, Fabry and others. It was soon realized that the light from the known telescopic stars was insufficient to account for the intensity of the background illumination and theories as to additional sources were put forward.

A permanent auroral illumination was discovered whose chief line in the green region of the spectrum was visible practically every night to Campbell in California where aurora very rarely occur. Spectra were obtained by Slipher to determine its wave length and precise measurements were later made by Babcock using the interferometer.

*Lord Rayleigh, Proc. R. Soc. May 1928.

The variation in intensity and spectral character of this general auroral illumination has been the subject of investigation by Rayleigh for a decade. By using screens isolating different regions of the spectrum he was able to show that the light of the night sky was much less blue than that of sunlight, a result which weighed heavily against the theory of its being due to sunlight reflected from a gaseous atmosphere high up.

From his spectra secured with a low dispersion spectrograph in 1921 Rayleigh showed that no connection existed between the strength of the green line and the character of the magnetic variations. Climatic conditions in England being unfavourable for such spectrographic work, he resorted to visual methods, using three filters to isolate the red, auroral and blue regions of the spectrum. The light of the night sky after passing through the auroral filter, say, was matched by means of suitable neutral glasses with the weak luminescence of a radio active salt.

The variations found were greater by far than could be accounted for by possible variations in atmospheric transmission and accordingly a co-operative scheme of observing these variations was developed. A dozen instruments, standardized with his own, were placed with observers all over the world, one being assigned to the Victoria observatory. The results now worked up by Rayleigh show that, while the mean values for the light of the night sky for each of the filters are nearly alike the world over, yet large variations in each occur. No correlation can be found among the widely separated stations as regards these irregular variations. Studying the records from each place separately, however, as for example his own in England, he found periodic variations suggestive of an annual increment and decrement with the sun's varying declination. Moreover, though his observations were for a period less than five years, they showed a progressive increase in the strength of the auroral component in harmony with the solar cycle of 11.5 years.

He prefers to consider this general auroral illumination as entirely distinct from the polar aurora and with more sensitive methods of measuring intensities is now seeking to correlate the variations at stations of limited distances apart.

W. E. HARPER.

AMERICAN ASTRONOMICAL SOCIETY

By R. S. DUGAN, Secretary

The forty-first meeting of the Society was held in affiliation with the American Association for the Advancement of Science in New York City, December 26-29, 1928.

The four sessions for papers were held jointly with Section D in the Physics Building of Columbia University on Thursday, Friday, and Saturday.

President Brown opened the session on Thursday morning and then invited Mr. Schlesinger to take the chair—a good selection for the program, which was made up of papers on parallax and proper motion. These were contributed chiefly by the staffs of the Van Vleck and McCormick observatories.

In the afternoon the Society had the pleasure of hearing two papers from the Coast and Geodetic Survey and one by R. H. Curtiss, telling of the initiation of regular observing at the Lamont-Hussey Observatory in South Africa. A fine set of slides of the planets from the Lowell Observatory was shown.

On Friday morning a group of astrophysical papers was given with Professor H. H. Turner, honorary member of the Society, and Mr. Fox, secretary of Section D, presiding. The presidential address of George C. Comstock, entitled "The Atmospheric Refraction," was read on Saturday morning by Mr. Stebbins. Mr. Curtiss was then called to the chair and the remainder of the papers presented.

Thirty-three papers were accepted for the program: twenty-nine were presented; three were read by title; and the fire laws of New York City prevented the exhibition of a Fox Film. The margin between the 270 minutes scheduled for the twenty-nine papers and the 480 minutes actually used for the sessions was not wasted. Professor Turner's contributions to the discussion were especially appreciated. Three lanterns were tried and it is hard to say which was the best one.

At the Friday afternoon joint session of section B and D, the

Physical, Meteorological, and Astronomical societies, at the American Museum of Natural History, Mr. Nicholson read the address of the retiring vice-president of Section D, Walter S. Adams, on the possibilities of the proposed 200-inch telescope. Each member probably thought that if this telescope could be devoted entirely to his own particular problem astronomical science would take a step forward. W. J. Humphreys then gave his address on "Samples of Outdoor Physics." He was followed at a "general session" by H. H. Turner, of Oxford, the invited representative of the British Association, who, in "A Scientific Retrospect," carried the audience back to Kapler, Tycho, and Newton. These addresses will be printed in *Science*.

Some of the members are accustomed to the luxury of a rising floor; few had experienced the novelty of going up to the telescope in an elevator until they visited the Observatory on the roof of the Physics Building on Saturday afternoon. Everything looked nice and new and convenient. On Friday the bronze literary lady and the Society were photographed in front of the Columbia University Library.

The Society is especially indebted to Mr. J. W. Eckert and to Mr. Clyde Fisher for the many thoughtful ways in which they effectively worked for the comfort of the members and the success of the meeting.

Some members went to all the receptions and evening lectures, several shows, and the concert of the New York Philharmonic-Symphony on Sunday afternoon, ending up with Mr. Shapley's conducted tour through "Galaxies of Galaxies" and return in time to "catch the 10:45 for Yonkers," January 1, 1929.

Since it has become necessary to make certain changes in the Constitution in order to make it consistent with the articles of the recent incorporation, the Council thought it well to use the occasion for a thorough revision of the Constitution. A committee authorized by the Council to consider advisable changes was appointed by the president as follows: F. Schlesinger, F. Slocum, J. Stebbins, chairman. Alliteration of surnames and absence of middle name promises unanimity. The committee invites suggestions from other members and promises to give them due consideration. The results

of their findings will be submitted to the Society at the next meeting.

The nominating committee, Alice H. Farnsworth, Harlan T. Stetson and Warren K. Green (chairman), after long and presumably careful consideration proposed the following slate:

For Vice-President	1929-31	R. G. Aitken
Secretary	1929-30	R. S. Dugan
Treasurer	1929-30	Benjamin Boss
Councillors	1929-32	E. S. King
		F. H. Seares
Member of Div. of Phys. Sciences, N.R.C.,	1930-33	S. A. Mitchell

This report was approved by the Council and these nominations will form the official ticket to be submitted to the Society at the annual meeting. The secretary is authorized to invite other nominations, which, if made by at least ten members and received by the secretary before May 1, will be printed and distributed with the official ballot.

John A. Miller and Heber D. Curtis have been appointed official representatives of the Society at the Fourth Pacific Science Congress, which will be held in Batavia and Bandoeng, Java, May 16 to 25, 1929.

The following persons were elected to membership. The number of members in the Society, with, however, no allowance for unpaid dues, is four hundred and eighty-five:

Sten Asklof, Leander McCormick Observatory, University, Va.
Leland S. Barnes, Lehigh University, Bethlethem, Pa.
Dirk Brouwer, Yale University Observatory, New Haven, Conn.
George A. Davis, Jr., 936 Elliott Square, Buffalo, N.Y.
Guy Emerson, 150 East 73rd St., New York City.
Grace C. Jordan, 345 Central St., Springfield, Mass.
Charlotte M. Krampe, 1101 15th St. N.W., Washington, D.C.
Paul A. McNally, Georgetown College Observatory, Washington, D.C.
John E. Merrill, 275 Nassau Street, Princeton, N.J.
Nicolas Perrakis, University of Paris, Paris, France.
Dirk Reuyl, Leander McCormick Observatory, University, Va.
L. V. Robinson, Harvard College Observatory, Cambridge, Mass.
Helen F. Story, Wellesley College, Wellesley, Mass.
Fred L. Whipple, 1298 E. 4th St., Long Beach, Calif.
Vera M. Gushee, Pine Manor School, Wellesley, Mass.

The attendance broke the record previously held by the 30th meeting at Mt. Wilson by a considerable margin. The following members were present:

Sebastin Albrecht, Leah B. Allen, Adelaide Ames, L. B. Andrews, L. S. Barnes, Ida Barney, S. G. Barton, Harriet W. Bigelow, William Bowie, Dirk Brouwer, E. W. Brown, Leon Campbell, Annie J. Cannon, C. A. Chant, W. A. Cogshall, C. H. Currier, R. H. Curtiss, G. K. Daghlian, A. E. Douglass, R. S. Dugan, J. C. Duncan, W. J. Eckert, W. S. Eichelberger, Alice H. Farnsworth, E. A. Fath, J. W. Fecker, G. C. Fisher, Philip Fox, Caroline E. Furness, Carolyn Gesler, C. H. Gingrich, W. K. Green, Vera M. Gushee, Mrs. H. T. Hall, J. C. Hammond, Margaret Harwood, William Henry, W. J. Humphreys, A. G. Ingalls, Harold Jacoby, Grace C. Jordan, M. F. Jordan, D. K. Kazarinoff, M. S. Kovalenko, W. D. Lambert, Mrs. C. L. Lewis, Morris Liferock, F. B. Littell, Hazel M. Losh, C. A. R. Lundin, P. A. McNally, D. B. McLaughlin, E. S. Manson, Jr., R. W. Marriott, Antonia C. Maury, A. D. Maxwell, C. E. K. Mees, J. E. Merrill, J. A. Miller, S. A. Mitchell, Charlotte E. Moore, D. W. Morehouse, F. R. Moulton, J. J. Nassau, S. B. Nicholson, Jesse Pawling, D. B. Pickering, J. H. Pitman, J. M. Poor, I. G. Priest, Harry Raymond, Dirk Reuyl, E. D. Roe, Jr., Alice Rogers, C. E. Rogers, J. T. Rorer, Jan Schilt, Frank Schlesinger, Harlow Shapley, B. W. Sitterly, Frederick Slocum, C. L. Stearns, Joel Stebbins, H. T. Stetson, J. Q. Stewart, R. M. Stewart, James Stokley, N. W. Storer, Henrietta H. Swope, A. B. Turner, H. H. Turner, Mrs. P. S. Underwood, R. N. Van Arnam, George Van Biesbroeck, Piet van de Kamp, W. J. Vinton, Alexander Vyssotsky, R. L. Waterfield, C. T. Whitehorn, E. L. Williams, Emma T. R. Williams, Marjorie Williams, R. E. Wilson, J. E. G. Yalden, Jessica M. Young.

The list may not be entirely complete but is nearly so. The following attendance of visitors was recorded:

Edward Arnott, A. D. Carpenter, E. H. Clarke, W. M. Cody, Mrs. Dugan, Mrs. Duncan, Miss Isobel Harris, Y. Hagihara, Mrs. Hammond, Miss Rebecca Hubbell, L. Hufnagel, Miss Selma Kenarney, Miss Eleanor Knight, S. A. Korff, Mrs. Kovalenko, Raymond Lewis, Mrs. Littell, Mrs. Mary F. Losh, Mrs. Lundin, Miss Lundin, Miss Georgette Maulbetsch, Mrs. Mitchell, C. M. Olmsted, Harry W. Reddick, James Robertson, J. Rosenman, Mrs. Slocum, W. M. Smith, Arthur Snow, C. L. Snow, G. W. Walker, Miss Henrietta Young.

It was announced that the next meeting would be held at the Dominion Observatory, Ottawa.

REVIEW OF PUBLICATIONS

The Pageant of the Stars, by W. J. Luyten, Assistant Professor of Astronomy in Harvard University. 300 pages, 16 plates, 5x8 in. Doubleday, Doran & Co., 1929. Price $2.50.

This book is written for the layman. Its distinguishing feature is its discussion of great cosmic problems, such as the origin of the solar system, the age of the earth, the source of the sun's energy, why the moon always shows the same face to the earth, the origin of comets, the causes of novae, the nature of nebulae, and so on.

The author is familiar with the latest discoveries and theories and the reader is supplied with the very latest views propounded by the leading astronomers. Sometimes the speculative nature of these views is not very clearly indicated, and the reader may find considerable alteration in them within ten years.

The plates are good and show some remarkable objects. The diagrams are not so satisfactory—rather few in number and not very clearly drawn. Throughout the book there are many apt comparisons, many of them referring to objects in New York City,—as for example in explaining the proper motion of Sirius which, to the astronomer, is very large, but "as seen by an observer standing on top of the Woolworth building, Sirius, when watched for a whole year would be found to move by the thickness of a half-dollar placed on Broadway."

Dr. Luyten, I believe, is a Hollander by birth and training, but one would not suspect it from the language which he uses. It is simple, clear and has numerous flashes of humour. C.A.C.

The Two Solar Families, by Thomas Chrowder Chamberlin. 333 pages, 4¾x7½ in. Chicago: University of Chicago Press; Toronto: The Macmillan Co. of Canada. 1928. Price $2.50.

This is an attempt to trace the parentage of the planetary family

and the cometary family back to successive encounters between our sun and two other suns of space.

To enunciate a reasonable theory of cosmic evolution and to defend it against all attacks, demands a knowledge of many branches of science, such as, celestial mechanics (including the various parts of dynamics), physics, chemistry and geology. The majority of such theories have come from the mathematico-physical side; this is from the geological side.

Its author was one of the original members of the faculty of the University of Chicago and a well-known authority in geology. The present work was published on his 85th birthday, September 25, 1928. He died on November 15. It is evidence of his strength of intellect to the end.

Through his difficulty in accounting for glacial phenomena upon the old nebular hypotheses, Professor Chamberlin was led to propose in 1901 the Planetesimal hypothesis. In working it out he was assisted by Prof. F. R. Moulton.

The present work in a sense supersedes the author's book on "The Origin of the Earth." It is non-mathematical in form. The first 82 pages are devoted to an elaborate refutation of the older nebular hypothesis; the rest of the book is constructive and endeavours to show how the various features of the planetary and cometary families can be accounted for on the dynamical encounter and planetesimal view.

All such theories must, to a certain extent, be unsatisfactory. Many factors involved are indefinite in form or quantity, and new phenomena are continually being discovered which require an adjustment of the argument. But it is most desirable to have a clear statement of the latest form of a theory by a master of it, and especially so if he is the real originator of it. For this reason the present volume will be welcomed by geologists and astronomers.

A few slips have been detected. On p. 70 it is stated that Hall discovered the satellites of Mars in 1868 instead of 1877, and fig. 46 (p. 265) is a picture of Brooks's comet, Oct. 23, 1911, not of Morehouse's as stated. C.A.C.

The Fundamentals of Astronomy, by S. A. Mitchell and C. G. Abbot. 306 pages, 5¼x8½ in. N.Y.: Van Nostrand, 1928. Price $3.00.

For a number of years there was a drought of up-to-date text-books on Astronomy, and then came almost a downpour. This book arrived at the end of the shower. One of the authors is widely known for his work on eclipses and stellar parallaxes; the other for his persistence and devotion in tracking down the mysteries of the radiation of the sun. As we might expect, these subjects receive special attention in the book.

Within the compass of 300 pages it is a serious problem to give an understandable account of the ever-widening developments of astronomy, and no two authors would divide the space in the same manner. An unusual feature of the book is the chapter of short biograhpies near the beginning. They are written with a full knowledge of the subjects treated and are well done; but it is a question whether a beginner in a science has sufficient information to appreciate the fine points in a biographical sketch of a worker in that science. However, if they arouse the interest of the reader perhaps they are justified.

More space than usual is given to the calendar, which is a matter of general interest now. There are also a number of anecdotes of astronomers scattered through the book. The present writer wonders if enough attention is given to the celestial sphere and its fundamental circles.

The last four chapters deal with stellar spectra, the interpretation of spectra (including protons, electrons and quanta), the system of our stars, building the universe. In them is a brief account of the chief problems which the astrophysicist has been trying to solve during the last two decades.

The half-tone illustrations are numerous and are excellent, and the whole book is attractively produced. One is not surprised that a second printing was called for eight months after the first.

C.A.C.

A Manual of Laboratory Astronomy, by H. T. Stetson, with the collaboration of J. C. Duncan. New edition. 185 pages, 5¼x8 in. Boston: Eastern Science Supply Co., 1928. Price $2.25.

It is very encouraging to learn that this is the fifth printing of this work. It first appeared in loose-leaf form in 1924. In the present edition much has been added and many changes have been made.

To produce a laboratory manual in any branch of science, which will be suitable for general use, is a very hard task. The conditions vary so greatly from place to place and each instructor has his own ideas of presenting the subject.

This volume contains 42 exercises—on the constellations, the earth, moon, planets, the sun, the stars and instruments. Full instructions are given regarding procedure and references are given to text-books.

The apparatus described is supplied by the Eastern Science Supply Co., which deserves high commendation for developing this branch of elementary science. Chemistry and physics have long been well served by the instrument makers. Astronomical laboratory work is harder to reduce to a system, but this work gives an outline of a workable and useful series of exercises. If the student performs them and understands them he will have a good knowledge of elementary astronomy. C.A.C.

NEWS AND COMMENTS

Professor V. V. Michovitch has been appointed Director of the Astronomical Observatory, Belgrade, Yugoslavia. He is anxious to build up the library and would appreciate the receipt of any publications addressed to 52 Voivoda Milenko, Belgrade.

The Janssen gold medal of the Paris Academy of Sciences has been awarded to Dr. W. H. Wright of the Lick Observatory for his investigations of the planetary atmospheres.

The gold medal of the Royal Astronomical Society (London) has been awarded to Professor Ejnar Hertzsprung of Leiden Observatory for his determination of the distance of the Magellanic Clouds and other pioneering work in stellar astronomy (*Nature*).

The Swarthmore College expedition under the leadership of Dr. John A. Miller, professor of astronomy, left on January 15 for Takengon, Sumatra, in order to prepare for the eclipse of the sun on May 9. This is the fifth expedition sponsored by the Sproul Observatory (*Science*).

The eclipse of the sun on May 9 will be observed by an expedition under the auspices of the Naval Observatory, Washington, which sailed for the Philippines on January 28, on the naval transport *Chaumont*, from San Diego, Cal. Commander C. H. J. Keppler is in charge of the expedition, while the scientific work is under the direction of Professor Wilbur A. Cogshall, of the University of Indiana. Mrs. Cogshall accompanies him as scientific assistant. The staff of the Naval Observatory is represented by Mr. Paul Sollenberger, the technical supervisor of the observatory's time service and an expert observer. Several other expeditions are to cover observations on its own part, is duplicating certain features of the program arranged for the party from Sproul Observatory. An interesting comparison of data is in prospect if both parties are favoured with clear weather. Several other expeditions are to cover the many phases of this exceptional eclipse (maximum duration of totality being over five minutes). British expeditions from Greenwich and Cambridge are in prospect. Four German expeditions are

planned, one from Hamburg, possibly operating in the Philippines. Then there are Dutch, French and Italian expeditions in preparation, and possibly one from Australia (*Science*).

Mr. A. H. Miller of the Dominion Observatory left Ottawa on February 14 for a two weeks' visit to Washington to complete the tie-up of gravity measurements between Europe (Greenwich and Potsdam) and America (Washington and Ottawa). On February 16 he addressed the Philosophical Society of Washington on this subject and on the Gravity Survey of Canada. REDeL.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Visibility of the Crescent Phase of Venus

In the last issue (p. 48) was a letter from Mr. Carl Reinhardt, of Cobalt, Ont., regarding the visibility of the phases of Venus with the naked eye. Under date January 26, Mr. Reinhardt gives the following interesting references to this subject:—

In Layard's "Nineveh and its Remains", Vol. 2, p. 346, and "Nineveh and Babylon", p. 606, are illustrations of sculptures of one of the forms in which the deity, Hera or Astarte, the Assyrian Venus, appears. In her left hand she bears an emblem resembling the symbol still used to represent the planet Venus: in her right hand she bears a staff tipped with a crescent.

Of this, R. A. Proctor says: ("Saturn and its System", p. 197) "It may, therefore, be noticed as, at the least, a singular coincidence that the crescent should be found associated, not with the deity representing the moon, but with the deity representing a planet whose appearance never affords any indication to the unaided eye of the crescent form."

The finding by Layard of a lens of rock crystal, led Proctor to suspect that the Assyrians might have invented the telescope, since, besides the above fact, they represented the deity, Jupiter, with four stars, and Saturn with a circle about him.

Subsequently, however, further facts must have come to Proctor's notice, for, in "The Orbs Around Us", written seven years afterwards (in 1872) he says: (p. 102), "To vision such as ours, the earth (as seen from Venus) must present the figure of a disc, because we know that, under favourable circumstances, we can ourselves recognize the crescent form of Venus with the unaided eye."

I have also found a news article (author not stated) as follows: "Can the crescent which Venus now shows be seen with the naked eye? It is said to have been thus seen by the man servant of a well known amateur astron-

omer in Ireland. The performance of the feat is, however, a very debatable point indeed. On the whole, the balance of scientific opinion is against the visibility of the crescent without optical aid."

I do not think I ever had exceptionally keen eyesight, however, and believe that anyone with ordinary good sight can repeat my observation when Venus comes to her greatest brilliancy, provided atmospheric conditions are right, and the method of the ancient Mayas and Egyptians be followed, of making their observation from a darkened room in their temples through slits or windows in the wall.

Since Venus is of such dazzling brightness, its glare after dark would probably be too great to expect success, and better results might be obtained even before the sun set, rather than after, as is the case with telescopic observation.

Sun Spots and Radio Reception

Of all the papers presented at the recent meeting of the American Astronomical Society in New York City, that one referring to a definite relation between sun spots and radio reception has the greatest interest to the public at large. Following is a synopsis of it as given by *Science News-Letter*:—

The poorest radio reception for many years may be expected during the latter half of 1929 because of the large number of spots on the sun due at that time, Prof. Harlan T. Stetson of the Harvard Laboratory of Astronomy predicted when he described three years of researches connecting radio receiving conditions on earth with changes in the atmosphere of the sun.

One of the reasons that radio broadcasting developed so rapidly is that at the time of its rapid growth, about 1923, sun spots were at a minimum and at no time since has radio reception been so favorable, Prof. Stetson explained. Equally good receiving conditions will not return again until the present sun spot cycle terminates in 1934.

The popular impression that radio reception is universally poor in summer and good in winter is "completely unfounded," Prof. Stetson declared. If shortened days and decreased daylight which aid radio were the only factors, the popular idea would be correct, but during the winters of 1926 and 1927 increased activity on the sun made the cold seasons better radio periods than the summers. Decreases in sun spots during the last two months of this year have improved receiving conditions greatly. Prof. Stetson explained that static due to thunder storms in summer causes the average radio listener to decrease his set's sensitivity and thus appear erroneously to get low signal intensity in warm weather.

A definite fourteen to fifteen month period in both radio and solar activity was discovered by Prof. Stetson's researches conducted in coöperation with Greenleaf W. Pickard of Newton Center, Mass. One of these secondary maxima falling due next September or October and coinciding with the longer sunspot cycle of about eleven years will probably make the sun more spotted and the radios more unhappy than they have been for years. C.A.C.

MEETINGS OF THE SOCIETY

AT VICTORIA

Nov. 13.—The second meeting of the fall term was held in Victoria College at 8.00 p.m., the President, J. A. Pearce, occupying the chair.

Mr. R. O. Redman described the telescopic appearance of Jupiter, illustrating his remarks by 3 lantern slides. The weather did not permit the members to observe the planet, as had been planned.

The following were elected members:

Capt. C. H R. Slingsby, 2187 Oak Bay Ave., Victoria, B.C.

R. O. Redman, M.A., Dominion Astrophysical Observatory, Victoria, B.C.

The President spoke about the healthy state of the Victoria Centre as shown by the steady increase in our membership, there being 96 now on the roll as compared with 81 at the beginning of the year.

Seven members of the Society living in Western Canada had expressed their desire to affiliate with the Victoria Centre. The Council, at the meeting of November 24th, had confirmed their affiliation. The Secretary read their names as follows:

H. C. B. Forsyth, Esq., 3425 Point Grey Rd., Vancouver, B.C.

S. Humphrey, Esq., M.A., Unity, Sask.

Mrs. M. A. Kelk, Alert Bay, B.C.

W. S. Lougheed, Esq., Port Haney, B.C.

T. H. Lennox, Esq., B.A., Youngstown, Alta.

A. B. MacKay, Esq., M.A., LL.B., Calgary, Alta.

Henry Olden, Esq., 327 32nd St., S.W., Medicine Hat, Alta..

The President then called upon Mr. P. H. Hughes to describe the circumstances of the total eclipse of the moon taking place on the night of November 27-28. Mr. Hughes showed the members a slide illustrating the transit of the moon through the earth's shadow, and lucidly explained the various phases of the eclipse.

The address of the evening then followed. Dr. J. S. Plaskett, F.R.S., gave a most interesting account of the Leiden Meeting of the International Astronomical Union which he attended as a representative from Canada. His remarks were splenddly illustrated with lantern slides made from his own photographs, giving some very delightful and intmate glimpses of famous astronomers off duty outside of the conference room and observatory.

This personal aspect of the conference was varied by a brief outline of the more important happenings at the conference itself and among which were the reports of the commission on notation, which dealt with the redefining of the boundaries of the constellations, the commission on time, which recommended the substitution of the term Greenwich Mean Astronomical Time for Greenwich Mean Time as heretofore used; the report of the commissions on solar physics, eclipses, wireless signals, variable stars, radial velocity, classification of stellar spectra, etc.

It was recalled that Germans were present at the Union meetings this year for the first time, not as official members, but as specially invited guests of the President. Germany is not yet a member because of the disinclination shown by some of her astronomers at the time the invitation was first extended to them. Several of the Leiden Conference members had gone on to Heidelberg after the close of the Astronomical Union meetings and had attended the sessions of the Astronomische Gesellschaft, enjoying meeting again with the German scientists and being shown great hospitality.

Among the amusing incidents recalled by Dr. Plaskett was his effort at Haarlem to learn something more about one of his boyhood heroes, the Dutch boy who saved his country from inundation by sticking his finger in a hole in the leaking dyke. Seriously he had questioned the good people of Haarlem about this, but they shook their heads. No one there had ever heard the story.

An interesting description was given of the vast land reclamation scheme which Holland has under way. By this 550,000 acres would be reclaimed along the Zuyder Zee, the dyke to cost $55,000,000. No people but the Dutch, long accustomed to such problems, would have ventured the undertaking.

Examples of the comparatively low prices which still continues in Europe were given. A three day journey up the Rhine had cost only $11, berth included. Holland they had found remarkable for the industry and great activity of its people, the principal present-day industry seeming to be brickmaking. The trip up the Rhine had been notable for the revelation which it afforded of the Germans' cult for the open air life and sun baths. This was as remarkable to-day as the Germans' habit of beer-drinking had been in pre-war days. Visitors from this continent had also been much struck by the intensive cultivation carried on along the slopes of the Rhine.

Among the educational institutions of Germany which were specially commented on were the Planetariums, domes in which the public could see illustrated the complete procession of the heavens. There are about fifteen of these buildings in Germany, erected at a cost of about $70,000 each. Dr. Plaskett questioned, however, if they were of as much value in a scientific way as the same amount of money expended in an observatory.

Many beautiful views of London, Oxford, Cambridge, Norwich, Gloucester, and other English cities were shown, with a notable emphasis on the fine architectural features of each.

On motion of Mr. F. Napier Denison, seconded by Mr. F. Farrington, a hearty vote of thanks was returned to Dr. Plaskett for his lecture.

On motion of Dr. J. S. Plaskett, seconded by Prof. P. H. Elliott, Mr. W. T. Bridge was appointed auditor, vice Mr. H. H. Plaskett.

Annual Meeting, Dec. 4.—The Society met in the Victoria College at 8.00 p.m., the president, J. A. Pearce, in the chair.

On motion the minutes of the ordinary meeting of November 13th were taken as read.

The following were elected members:

1. Capt. J. N. Hughes, Meteorological Observer, Mill Bay, B.C.
2. Edmund P. Kay, Esq., 1721 Richmond Ave., Victoria, B.C.
3. F. T. Coverdale, Esq., 738 Yates St., Victoria, B.C.
4. John H. Bartlett, Esq., R.M.D. No. 1, Duncan, B.C., proposed by F. N. Denison and J. A. Pearce.

The minutes of the annual general meeting of 1927 were read and confirmed.

The reports of the Secretary-Treasurer for the year 1928 were read by acting-secretary, W. Gage, and adopted.

Messrs. W. T. Bridge and R. Bewell were appointed scrutineers to count the ballots for the election of the 1929 officers.

Prof. P. H. Elliott took the chair and called upon the President to address the meeting upon the subject "Our Wonderful Universe".

The address was richly illustrated by lantern slides selected from the splendid set of 100 slides recently prepared by Dr. C. A. Chant. The lecturer reviewed the primitive conception of the world as flat and stationary at the centre of the Celestial sphere and the geometric system of the Greeks and Ptolemy. The development of the heliocentric system, through the labours of Copernicus, Tycho, Kepler, Galileo, Newton and the famous astronomers of the past two centuries was briefly described.

The chief characteristics of the solar system were then discussed, and many illustrations were given in comparing the relative sizes of the sun and planets—isolation of the system from neighbouring stars, etc. Slides were shown of each of the planets and their significant features mentioned.

The stars of the local cluster were then surveyed; among the stellar characterstics discussed were visual and spectroscopic binary stars such as Kruger 60, Sirius, Procyon and Y Cygni; variable stars such as Algol and Mira; the Giant Stars, Antares and Mira, were compared with the dwarfs, such as Wolf 359, a star the size of the planet Uranus; the motions of the sun and stars were described; stellar spectra and evolution were outlined.

Photographs were then shown of the distant objects in the stellar system, the diffuse Galactic Nebulae, both dark and luminous; great star clouds in the Milky Way; the Magellanic Clouds; and star clusters such as N.G.C. 6822, approximately 200,000 light years distant.

The lecture closed with a brief discussion of the forms, distances, number and nature of the spiral nebulae. As a fitting conclusion the President read a poem recently composed by Kilbee Gordon of Victoria, B.C., entitled "How Marvellous the Heavens".

A motion of thanks was introduced by Dr. J. S. Plaskett, seconded by F. N. Denison.

The scrutineers reported that rather than miss the lecture they had adjourned to meet to-morrow evening, and that the results of the election would be announced in the daily papers.

The President then resumed the chair and announced the date and subject of Mr. W. E. Harper's lecture. The meeting was then adjourned, the members spending a pleasant hour in observing Jupiter, Mars, the Pleiades and the Orion Nebula through the 3½ inch refractor.

W. GAGE,
Acting Secretary.

AT TORONTO

December 18, 1928.—The regular fortnightly meeting was held in the Physics Building of the University of Toronto. Mr. J. R. Collins in the chair.

Three nominees for membership as follows were duly elected—

Mr. Roy Marshall, 87 Park Avenue, Delaware, Ohio.
Mr. Wilfred Gibbs Schroeder, 6540-5th Avenue, Kenosha, Wis.
A. D. Armour, Esq., K.C., Confederation Life Bldg., Toronto.

The Chairman gave the important predictions of phenomena for the month as recorded in Society's HANDBOOK.

Mr. A. F. Hunter called attention to the fact that the term of office of the members of the programme committee for the Toronto meetings had expired. He therefore, took pleasure in moving that the same board be re-elected for another year, with the addition of Miss Budd and Mr. H. W. Barker. Mr. Miller seconded the motion, which was carried.

Mr. Collins, in referring to Novae, stated that Mr. A. F. Miller had made a special study of some of the recent appearances of these phenomena and called on him for some remarks. Mr. Miller then recounted briefly his observations, particularly with reference to the Nova in Perseus.

The speakers for the evening were Mr. E. J. A. Kennedy, and Mr. S. C. Brown. The subject, "The Winter Constellations."

Mr. Kennedy's talk was in the nature of an introduction for Mr. Brown, who outlined clearly and interestingly the constellations seen during the winter months. With the aid of a chart, which he had prepared at some cost of time, Mr. Brown gave the interesting features of not only the well-known but also the smaller constellations appearing to the observer at this time of the year.

E. J. A. KENNEDY,
Secretary.

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The objects of the Society, incorporated in 1890, are:

(*a*) "To study Astronomy, Astrophysics and such cognate subjects as shall be approved of by the Society and as shall, in its opinion, tend to the better consideration and elucidation of Astronomical and Astrophysical problems; and to diffuse theoretical and practical knowledge with respect to such subjects.

(*b*) To publish from time to time the results of the work of the Society; and,

(*c*) To acquire and maintain a Library, and such apparatus and real and personal property as may be necessary and convenient for the carrying into effect of the objects of the Society."

For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal, P.Q.; Ottawa, Ont.; Toronto, Ont.; London, Ont.; Winnipeg, Man.; and Victoria, B.C. Among its 800 members are a number of the leading astronomers and scientists of the world, many amateurs, and in addition, many laymen who are interested in the culture of the science.

Membership in the Society is open to anyone interested in Astronomy. The annual dues are $2.00; life membership $25.00 (no further dues). The annual fee includes subscription to the publications.

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